



EUROPEAN PATENT APPLICATION

Application number: 94120109.7

Int. Cl.⁶ H01J 17/49, H01J 17/20

Date of filing: 16.07.92

This application was filed on 19 - 12 - 1994 as a
divisional application to the application
mentioned under INID code 60.

Priority: 18.07.91 JP 202135/91
18.11.91 JP 301832/91
21.11.91 JP 306247/91

Date of publication of application:
19.04.95 Bulletin 95/16

Publication number of the earlier application in
accordance with Art.76 EPC: 0 524 005

Designated Contracting States:
DE FR GB

Applicant: NIPPON HOSO KYOKAI
2-1, Jinnan 2-chome
Shibuya-ku
Tokyo 150 (JP)

Inventor: Sakai, Tetsuo, c/o NHK Hoso Gijutsu

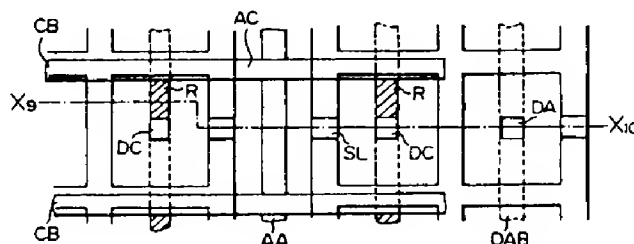
Kenkyusho
10-11 Kinuta-1-chome
Setagaya-ku,
Tokyo (JP)
Inventor: Motoyama, Yasushi, c/o NHK Hoso
Gijutsu Kenkyusho
10-11 Kinuta-1-chome
Setagaya-ku,
Tokyo (JP)
Inventor: Ushirozawa, Mizumoto, c/o NHK
Hoso Gijutsu
Kenkyusho,
10-11 Kinuta-1-chome
Setagaya-ku,
Tokyo (JP)

Representative: Senior, Alan Murray
J.A. KEMP & CO.,
14 South Square,
Gray's Inn
London WC1R 5LX (GB)

DC type gas-discharge display panel.

A DC type gas-discharge display panel comprises a plurality of discharge cells (DCE); discharge current limiting means (R) provided for each of the discharge cells (DCE), for limiting a discharge current of each of said discharge cells (DCE); and a filling gas filled into each of said discharge cells (DCE), and having an inert gas mixture. The discharge current limiting means (R) may be a resistor (R) formed between two adjoining lines of second conductive lines (AB) and second electrodes (A).

FIG. 46A



The present invention relates to a DC type gas-discharge display panel and a gas-discharge display apparatus using the DC type gas-discharge display panel.

First of all, the publications related to the present invention are listed as follows:

- (1). "A 17-in High Resolution DC Plasma Display" by Niwa et al., The Journal of the Institute of Television Engineers of Japan, Vol. 44, No. 5 (1990) pp. 571 - 577.
- (2). "A 20-in Color DC Gas-Discharge Panel for TV Display" by Murakami et al., IEEE Transactions on Electron Devices, Vol. 36, No. 6, June 1989, pp. 1063-1072.
- (3). "Ultra-Low Reflectivity Color Display Gas-Discharge Panel" by Sakai et al., The Journal of the Institute of Television Engineers of Japan Vol. 42, No. 10 (1988) pp. 1084-1090.
- (4). U.S. Patent No. 4,780,644, "Gas-Discharge Display Panel".
- (5). "Plasma Display Panel with a Resistor in each Cell" by Takano et al., Annual Convention of Institute of Television Engineers of Japan, 1990, Provisional Report 4-3, pp. 77-78.

A first conventional DC type gas-discharge panel has structure thereof as shown in Figs. 1A and 1B. Fig. 1A is a sectional view of this first conventional gas-discharge panel, and Fig. 1B is a plan view thereof, as viewed from a display side.

In Figs. 1A and 1B, symbol "FP" indicates a front plate (glass); symbol "BM", shows a black grid (black matrix); symbol "BA" is a partition; symbol "A" shows an anode (indium tin oxide); symbol "Ph" denotes phosphor; symbol "Ct" shows a cathode (Ni); symbol "D" indicates a dielectric material; symbol "TN" denotes a third electrode; and symbol "RP" shows a rear plate (glass). A detailed explanation of this gas-display panel is described in above-mentioned publication (1). In this panel, the display panel of the X-Y matrix is driven by the 1-line at-a-time drive method, and a relatively large current (about 490 μ A) flows therethrough. As a result, the light-emission efficiency is 0.025 lm/W (white), which implies a low efficiency, and therefore this display panel is not utilized as a color television receiver panel except for a TV receiver panel for special purposes. In this display panel, He (partial pressure ratio of 93%) - Kr (5%) - Xe (2%) gas is employed as the filling gas, and total pressure thereof is 53 kPa (400 Torr).

In Fig. 2, there is shown a second conventional DC type gas-discharge display panel. It should be noted that the same reference symbols shown in Figs. 1A and 1B are employed to denote the same constructive elements shown in Fig. 2. There are other reference symbols in which symbol "AA" indicates an auxiliary anode; symbol "R-Ph" shows red phosphor; symbol "G-Ph" indicates green phosphor; symbol "B-Ph" is blue-phosphor; symbol "PS" shows a priming slit; symbol "DC" is a display cell; symbol "W" represents a wall; and symbol "ACE" indicates an auxiliary cell. The operation of this second display panel is described in above-mentioned publication (2).

In Fig. 3, there is shown a third conventional DC type gas-discharge panel. It should be noted that the same reference symbols shown in Figs. 1A, 1B and 2 are employed to denote the same constructive elements shown in Fig. 3. Of the other reference symbols, symbol "F" indicates a filter; symbol "CB" denotes a cathode bus line; symbol "WB" shows a white back; symbol "AAL" is an auxiliary anode line, and symbol "DAL" denotes a display anode line. A detailed description of this third conventional display panel is found in above-mentioned publication (3).

Furthermore, Figs. 4A and 4B represent a fourth conventional DC type display panel. Fig. 4A is a plan view of this display panel, as viewed at a display side, and Fig. 4B is a sectional view thereof cut away along a cutting line $X_1 - X_2$ shown in Fig. 4A. The structure of this fourth display panel is most similar to that of a DC type gas-discharge display panel according to the present invention. It should also be noted that the same reference symbols shown in Figs. 1A to 3 are employed to denote the same constructive elements shown in Figs. 4A and 4B. Of the other reference symbols, reference symbol "AC" denotes an auxiliary cathode; symbol "DAB" shows a display anode bus line; and symbol "R" indicates a current limiting resistor. A detailed explanation of the fourth conventional display panel is found in the above-mentioned publications (4) and (5).

The above-described second to fourth conventional display panels are driven by the pulse memory drive method, the cathodes "C" of which are made of such materials as Ni, Al and LaB_6 , and in which He-Xe (1.5 to 5%) gas is employed as the filling gas. The total pressure of the display panel is from 27 to 33 kPa (200 to 250 Torr).

As previously described in detail in the above-mentioned publication (1), peak luminance of an image of the first conventional gas-discharge display panel is about 33 cd/m^2 , namely dark. Moreover, since the light-emission efficiency is not so high, this first display panel is not adequate to a display panel for a large-screen sized television receiver.

Although no description of the lifetime of this first display panel is given in the publication (1), a relatively long lifetime can be predicted, because the light emission duty which is inversely proportion to the line number of this display panel, is 1/480, namely low, and thus its luminance is lowered. Assuming now

that a "lifetime", is defined as the operation time during which present luminance of a display panel becomes 1/2 of initial luminance, generally speaking, when light emission duty is lowered to reduce luminance, when a comparison is made between the lifetimes of the display panels, luminance X lifetime should be employed as a comparison basis.

As to the second and third conventional display panels, the practical lifetimes may be predicted as 1,000 hours to 2,000 hours since luminance thereof is increased due to the memory function, and also peak luminance is from 50 to 100 cd/m². Since when luminance is 100 cd/m² 10,000 hours are required for a practical display, the predicted lifetimes of the second and third conventional display panels constitute a big problem.

It appears that the most important factor determining the lifetime of a display panel is that luminance of this display panel is reduced because sputtered cathode material adheres to the inside of the cells. The discharge current can be reduced so as to suppress the sputtering, so that the sustaining discharge currents of the second and third conventional display panels are suppressed to about 100 μ A, but the lifetimes thereof are still short.

To avoid the above-described drawback, a current limiting resistor is connected to the fourth conventional display tube, so that the sustaining current thereof is lowered and then the lifetime thereof becomes approximately 2 times longer than that of the second or third conventional display panel. However, this longer lifetime is not a practically sufficient lifetime.

As previously explained, a DC type gas discharge display panel with high luminance and a sufficiently long lifetime can not be realized from those conventional DC type gas-discharge display panels.

In, for instance, the DC type gas-discharge display panel shown in the above-mentioned publication (5), resistors for each of the discharge cells are employed in order to limit the discharge currents flowing through the respective discharge cells. This resistor functions to limit the discharge current of the discharge cell to the normal glow discharge region, to dissipate sputtering, and maintain the memory effect in the DC memory type discharge display panel.

Figs. 5A and 5B are schematic diagrams of a structure of this discharge display panel. Fig. 5A is a plan view of a portion of this discharge panel, and Fig. 5B is a sectional view thereof, taken along a cutting line X₃ - X₄. Also, there is shown in Fig. 5B a cutting sectional plane X₅ - X₆ in Fig. 5B. It should be noted that the same reference symbols shown in Fig. 1A to 4B are employed to denote the same constructive elements in Figs. 5A and 5B.

In this example, a cathode "C" is formed on a front plate "FP", both of an anode bus line "AB", and an auxiliary anode "AA" are formed on a rear plate "RP" and positioned perpendicular to the cathode "C", and also a discharge cell "DCE" surrounded by walls "W" are formed on the respective cross points between the anode bus line "AB" and the cathode "C". In the discharge cell "DCE", a resistive material "RM" having an L-shaped form is furthermore fabricated between the anode bus line "AB" and the anode "A".

Operation of this discharge display panel will now be summarized. When a predetermined voltage is applied to a specific cathode "C" and the anode bus line "AB", a current flows via the resistor R to the cells "DCE" at these cross points, so that a discharge occurs between the anode "A" and the cathode "C". The phosphor "Ph" emits light in response to ultraviolet rays produced by this discharge. Thus, the specific discharge cell "DCE" within the panel can emit light. The light is emitted from the specific cell through the front plate FP to the outside. Red, green and blue phosphors are employed for each of the discharge cells "DCE" to display a full-colored television image. The function of the white glass back "WB" is to electrically insulate the electrode and also to derive the emitted light at the high efficiency. A discharge is previously induced between the auxiliary anode "AA" and the cathode "C" so that the commencement of the discharge in the discharge cell is emphasized via the priming slit "PS".

In accordance with the above-described DC type discharge display panel, higher light-emission efficiency can be achieved with a small drive current, and also deterioration of the display panel caused by the sputtering can be prevented, thereby prolonging the lifetime thereof. To this end, the resistors "R" for limiting the discharge currents are employed in the respective cells "DCE".

In accordance with prior art, the L-shaped resistive materials to constitute the resistors have been separately formed with the respective cells.

A large-sized display panel is manufactured by way of, for instance, the thick-film printing method and the like. The conventional panel manufacturing method has a drawback that large fluctuation occurs in the resistance values, depending upon the manufacturing precision, e.g., the dimension and thickness of the resistive materials. Also, the resistance values vary in accordance with the positions and dimensions of the electrodes for terminating this resistor. If the resistance value varies, there are problems that the discharge currents of the respective cells change, and therefore the light-emitting outputs vary, and the variable light appears as fixed pattern noise on a displayed image. In other words, there is a problem that a lack of

luminous uniformity, or luminous fluctuation occurs in the respective discharge cells.

An object of the present invention is to provide a DC type gas-discharge display panel, with low luminous variation in each of discharge cells.

A DC type gas-discharge display panel according to the present invention comprises: a plurality of
 5 discharge cells arranged in a matrix form along a line (row) direction and a column direction; a plurality of resistors provided for each of said discharge cells, for limiting a discharge current of each of said discharge cells; a filling gas filled into each of said discharge cells; a plurality of first conductive lines elongated along the line direction to which one of a desirable discharge controlling potential is applied, each of said first
 10 conductive lines being commonly arranged in each of said discharge cells in the respective lines to constitute a first discharge electrode; a plurality of second conductive lines elongated along said column direction, to which the other desirable discharge controlling potential is applied, two adjoining lines of said second conductive lines being commonly arranged with the respective discharge cells; a plurality of second discharge electrodes provided at a substantially central position between each pair of adjoining second conductive lines, which corresponds to each of said discharge cells, for producing a discharge between said
 15 first discharge electrodes corresponding to said discharge cells; and a plurality of resistive materials elongated along said column direction, each of said resistive materials being arranged in such a manner that said discharge cells at said column are bridged by each of said resistive materials, and being in contact with both of said two adjoining lines of said second conductive lines and said second electrode corresponding to said discharge cells at each column, and, wherein each of said resistors is formed by
 20 being terminated by said two adjoining lines of said second conductive lines and said second electrodes corresponding to said respective discharge cells.

According to this DC type gas-discharge display panel, luminous variation of the respective discharge cells can be lowered without requiring high precision in the manufacturing stage.

A DC type gas-discharge display panel according to another aspect of the present invention, comprises
 25 a plurality of discharge cells arranged in a matrix form along a line (row) direction and a column direction; a plurality of resistors provided at each of said discharge cells, for limiting a discharge current of each of said discharge cells; a filling gas filled in each of said discharge cells; a plurality of first conductive lines elongated along the line direction, to which one of a desirable discharge controlling potential is applied, each of said first conductive lines being commonly arranged in each of said discharge cells in the
 30 respective lines to constitute a first discharge electrode; a plurality of second conductive lines elongated along said column direction, to which the other desirable discharge controlling potential is applied, each of said second conductive line being commonly arranged with the respective discharge cells positioned at the respective columns; plural pairs of branch conductive lines branched from each of said second conductive lines along said line direction in a comb shape, each of said pair of branch conductive lines being arranged
 35 at a position corresponding to each of said discharge cells; a plurality of second discharge electrodes provided at a substantially central position between said pairs of branch conductive lines for producing a discharge between said first discharge electrodes corresponding to said discharge cells; and a plurality of resistive materials elongated along said column direction, each of said resistive materials being arranged in such a manner that said discharge cells at said column are bridged by each of said resistive materials, and
 40 being in contact with both of said pair of branch conductive lines and said second electrode corresponding to said discharge cells at each column; each of said resistors being formed by said resistance materials being terminated by said pair of branch lines of said second conductive lines and said second electrodes corresponding to said respective discharge cells.

In accordance with this DC type gas-discharge display panel, luminous variations of the respective
 45 discharge cells can be reduced without requiring high precision in the manufacturing stage.

The present invention will be further described hereinafter with reference to exemplary embodiments and the accompanying drawings, in which:

Fig. 1A is a sectional view of the conventional DC type gas-discharge display panel, and Fig. 1B is a plan view thereof;

50 Fig. 2 is a perspective view of another 15 conventional DC type gas-discharge display panel, partially cut away;

Fig. 3 is a perspective view of another conventional DC type gas-discharge display panel, partially cut away;

Fig. 4A is a plan view of a further conventional DC type gas-discharge display panel, and Fig. 4B is a
 55 sectional view thereof, taken along a line $X_1 - X_2$ shown in Fig. 4A;

Fig. 5A is a plan view of a still further conventional DC type gas-discharge display panel, and Fig. 5B is a sectional view thereof, taken along a line $X_3 - X_4$ shown in Fig. 5A;

Fig. 6A is a plan view of a DC type gas-discharge display panel employed in an experiment to perform the present invention, and Fig. 6B is a sectional view thereof, taken along a line $X_7 - X_8$ shown in Fig. 6A;

Fig. 7 represents a characteristic curve of luminance deterioration;

Fig. 8 shows a characteristic curve of luminance deterioration;

Fig. 9 indicates a lifetime-to-pressure characteristic;

Fig. 10 represents a lifetime-to-pressure characteristic;

Fig. 11 shows a lifetime-to-pressure characteristic;

Fig. 12 shows a lifetime-to-pressure characteristic;

Fig. 13 shows a lifetime-to-pressure characteristic;

Fig. 14 shows a lifetime-to-pressure characteristic;

Fig. 15 indicates a lifetime-to-Xe partial pressure ratio characteristic;

Fig. 16 shows a lifetime-to-Xe partial pressure ratio characteristic;

Fig. 17 represents a lifetime-to-Kr partial pressure ratio characteristic;

Fig. 18 represents a lifetime-to-Kr partial pressure ratio characteristic;

Fig. 19 represents a lifetime-to-Kr partial pressure ratio characteristic;

Fig. 20 represents a lifetime-to-Kr partial pressure ratio characteristic;

Fig. 21 shows a lifetime-to-current characteristic;

Fig. 22 shows a lifetime-to-current characteristic;

Fig. 23 indicates a light-emission efficiency-to-current characteristic;

Fig. 24 indicates a light-emission efficiency-to-current characteristic;

Fig. 25 indicates a light-emission efficiency-to-current characteristic;

Fig. 26 indicates a light-emission efficiency-to-current characteristic;

Fig. 27 indicates a luminance-to-current characteristic;

Fig. 28 indicates a luminance-to-current characteristic;

Fig. 29 indicates a luminance-to-current characteristic;

Fig. 30 indicates a luminance-to-current characteristic;

Fig. 31 shows an electrode voltage-to-current characteristic;

Fig. 32 shows an electrode voltage-to-current characteristic;

Fig. 33 shows an electrode voltage-to-current characteristic;

Fig. 34 shows an electrode voltage-to-current characteristic;

Fig. 35 shows an electrode voltage-to-current characteristic;

Fig. 36 indicates a minimum sustaining discharge current-to-pressure characteristic;

Fig. 37 indicates a minimum sustaining discharge current-to-pressure characteristic;

Fig. 38 shows a light-emission efficiency-to-pressure characteristic;

Fig. 39 indicates a light-emission efficiency-to-Xe partial pressure ratio characteristic;

Fig. 40 shows a characteristic related to a luminance of auxiliary cells-to-Kr partial pressure ratio;

Fig. 41 indicates a characteristic related to a luminance of auxiliary cells-to-Xe partial pressure ratio;

Fig. 42 denotes a characteristic related to a luminance of auxiliary cells-to-pressure;

Fig. 43 represents a range for satisfying a predetermined condition;

Fig. 44 represents a range for satisfying a predetermined condition;

Fig. 45 shows a lifetime-to-pressure characteristic;

Fig. 46A is a plan view of a DC type gas-discharge display panel according to an embodiment of the present invention, and Fig. 46B is a sectional view thereof, taken along a line $X_9 - X_{10}$ shown in Fig. 46A;

Fig. 47A is a plan view of a DC type gas-discharge display panel according to another embodiment of the present invention, and Fig. 47B is a sectional view thereof, taken along a line $X_{11} - X_{12}$ shown in Fig. 47A;

Fig. 48A is a plan view of a DC type gas-discharge display panel according to another embodiment of the present invention, and Fig. 48B is a sectional view thereof, taken along a line $X_{13} - X_{14}$ shown in Fig. 48A;

Fig. 49A is a plan view of an essential part of DC type gas-discharge display panel according to another embodiment of the present invention, and Fig. 49B is a sectional view thereof, taken along a line $X_{15} - X_{16}$ shown in Fig. 49A;

Fig. 50A is a plan view of an essential part of DC type gas-discharge display panel according to another embodiment of the present invention, and Fig. 50B is a sectional view thereof, taken along a line $X_{17} - X_{18}$ shown in Fig. 50A;

Fig. 51A is a plan view of an essential part of DC type gas-discharge display panel according to a further embodiment of the present invention, and Fig. 51B is a sectional view thereof, taken along a line

$X_{19} - X_{20}$ shown in Fig. 51A;

Fig. 52A represents a positional relationship between an anode bus line and an anode, and a distance between adjoining anodes and also a potential relationship between them. Fig. 52B shows another positional relationship between an anode bus line and an anode, and also a potential relationship. Fig. 52C indicates a relationship between a resistance value and a distance between adjoining anodes positioned along the anode bus line;

Fig. 53A shows a relationship between the anode bus line and the anode; Fig. 53B indicates a variation in resistance values when the anode is positionally shifted to the anode bus line;

Fig. 54A shows a positional relationship between an anode bus line and an anode and a size of the anode; Fig. 54B indicates a variation in resistance values when a size of the anode is changed along a direction parallel to the anode bus line;

Fig. 55A indicates a positional relationship between an anode bus line and an anode and a size of the anode, Fig. 55B shows a variation in resistance values when a size of the anode is changed along a direction perpendicular to the anode bus line;

Fig. 56A denotes a positional relationship between a branch line from anode bus and an anode, Fig. 56B shows a relationship between a position of the anode with respect to a branch anode, and a resistance value; and

Fig. 57 is a diagram for explaining an active cathode area.

The historical background of the present invention will first be explained in detail. The factors affecting the lifetimes of a DC type gas-discharge display panel when driven in the pulse memory drive scheme, were confirmed by the inventors based upon several experiments. These experiments were performed in a DC type gas-discharge display panel shown in Figs. 6A and 6B. Fig. 6A is a plan view of this DC type gas-discharge display panel, and Fig. 6B is a sectional view thereof, taken along a line $X_7 - X_8$ of Fig. 6A. The same reference numerals shown in Figs. 1A to 4B will be employed to denote the same elements in Figs. 6A and 6B.

As the cathode material of this panel, Al, Ni, BaAl₄ and the like were employed. The cathodes "C" were formed by directly utilizing a portion of a bus line "CB", or an adhesion of the cathode material on the bus line "CB". A white glass material was employed as the cell partition "BA" and a white over-glaze layer "WB" was provided. As a red phosphor, (YGd)BO₃:Eu was pasted and printed/burned. Similarly, as a green phosphor, Zn₂SiO₄:Mn was pasted and printed burned, whereas as a blue phosphor, BaMg Al₁₄ O₂₃:Eu was pasted and printed burned. Various experiments confirmed the following facts (1) to (4).

(1) The lifetime of a DC type gas-discharge display panel under a sustained pulse operation in a pulse memory drive scheme is equal to the lifetime of the DC type gas-discharge display panel under a constant current drive, the duty "D" and the current value of which are the same as those of the above-described sustained pulse operation. The constant current drive implies that a discharge cell is driven in such a manner that a constant current flows only for a predetermined time period defined by a predetermined duty D ($D \leq 1$). It should be noted that the lifetime of the display panel operated in the constant current drive with $D \neq 1$ is equal to a value calculated by dividing the lifetime thereof operated with $D = 1$ by the value of D. For instance, a lifetime of the display panel driven under the constant current mode at $D = 1/60$ is equal to a value calculated by multiplying by 60, a lifetime thereof driven under the constant current mode at $D = 1$. Consequently, if the lifetime of a display panel driven under the constant current mode with $D = 1$ is measured, the lifetime of this panel driven under the constant current mode at an arbitrary duty "D" may be calculated based upon the measured lifetime.

(2) As shown in Figs. 7 and 8, the characteristic curves of luminosity deterioration of the DC type gas-discharge display panel (relative luminance-to-operation time (elapse of time) characteristic) may be approximated by formula of $[\exp(-bt) + c]$, where "b", "c" are constants, and "t" is operation time. Fig. 7 represents the characteristic curve of luminosity deterioration of the display panel shown in Figs. 6A and 6B, measured with aluminum (Al) used as a cathode material, whilst filled with a filling gas consisting of a He gas with partial pressure of 90% and a Xe gas with partial pressure of 10% at a total pressure of 26.6 kPa (200 Torr), and driven in constant current mode with $D = 1$ and $I = 100 \mu A$ ("I" denotes the current flowing during a predetermined time period defined by a duty D). For simplicity such measuring conditions are described as a measurement that the display panel, shown in Figs. 6A and 6B, with Al cathode, He - Xe (10%) and, 26.6 kPa (200 Torr) is operated in the constant current drive mode of $D = 1$ and $I = 100 \mu A$. Fig. 8 indicates the characteristic curve of luminosity deterioration measured under conditions that the display panel shown in Figs. 6A and 6B with Al cathode, Ne - Xe (10%) and $p = 20$ kPa (150 Torr) is operated in the constant current drive mode of $D = 1$ and $I = 150 \mu A$. Note that symbol "p" indicates total pressure.

(3) When the operation current "I" is increased, a lifetime "T" of a DC type gas-discharge display panel is rapidly shortened. It was found that for instance, when a light emission duty (luminous duty) is equal to 1 (namely, a duty D = 1), if I = 100 μ A, then T = 100 hrs (hours), whereas if I = 300 μ A, then T = 2 hrs.

(4) The lifetimes of a display panel operated under several different currents could be successfully predicted. That is to say, a method of evaluating the lifetimes of the display panel when values and operation times of write current I₁, and a sustain pulse current I₂ are different from each other, as in the pulse memory drive scheme, was found. This evaluation method will now be summarized. Assuming now that two characteristic curves of luminous deterioration are analogous to each other, the lifetime at a current value I₁ is T₁, and the lifetime at a current value I₂ is T₂, and also duties thereof are D₁ and D₂, a lifetime T for mixed conditions is given as follows:

$$T = (D_1/T_1 + D_2/T_2)^{-1}$$

For instance, in case of the pulse memory drive scheme assuming now that I₁ = 300 μ A, T₁ = 2 hr, D₁ = 1/2000, I₂ = 100 μ A, T₂ = 100 hr, D₂ = 1/60, the lifetime under only write current is T₁/D₁ = 4000 hr, whereas the lifetime under only sustain current is T₂/D₂ = 6000 hr. The lifetime T under the mixed condition is actually 2400 hr. Thus, it is shown the lifetime is shortened due to the large write current, even though the duty is very small.

From these facts, it could be seen that the lifetime of the above-described fourth conventional display panel is prolonged because the write current is small.

The conditions of the present invention, namely the conditions such as the compositions of the filling gas and total pressure thereof, were confirmed by performing various measurements, while changing the composition of the filling gases and the like in the DC type gas-discharge display panel shown in Figs. 6A and 6B, which has substantially the same construction as that of the fourth preferred embodiment.

For instance, as shown in Fig. 9, when a He - Xe (10%) filling gas (namely, a filling gas composed by a He gas with partial pressure of 90% and a Xe gas with partial pressure of 10%) is filled at total pressure of 40 kPa (300 Torr), a lifetime of a display panel is considerably prolonged. Also, when the total pressure of 33 kPa (250 Torr) of the filling gas is increased only by 10%, the lifetime of the display panel is increased about two times and thus exceeds 10,000 hrs. Within a range of total pressure between 27 and 47 kPa (200 and 350 Torr), in which the lifetime of the display panel is increased or prolonged, the luminance of this panel was substantially constant at approximately 50 cd/m². It should be noted that Fig. 9 represents a lifetime-to-pressure (total pressure of filling gas) characteristic obtained when a display panel with an Al cathode (no Ag is contained in the cathode material) and He - Xe (10%), as shown in Figs. 6A and 6B, is driven in the constant current mode under D = 1 and I = 60 μ A. Note that the lifetime shown in Fig. 9 has been converted into the lifetime with D = 1/60.

Furthermore, when the abscissa and ordinate of the graphic representation of Fig. 9 are changed to a logarithmic scale, a graphic representation as shown in Fig. 10 is obtained. This figure also includes measurement data for values of the current I of not only 60 μ A, but also 100 μ A, 150 μ A, and 200 μ A. It can be seen from the gradient of the curves shown in Fig. 10 that the lifetime of the panel is substantially proportional to between p⁵ and p⁶, ("p" indicates total pressure of filling gas).

Similarly, as shown in Fig. 11, for instance, when the Ne - Xe (10%) filling gas was filled at total pressure of 33 kPa (250 Torr), the lifetime of the display panel was considerably increased, or prolonged. Also, when the total pressure of 26 kPa (200 Torr) of the filling gas was increased by only 10%, the lifetime was prolonged about two times, and exceeded 10,000 hrs. As described above, the luminance was substantially constant, at 40 cd/m² within the total pressure range 20 to 40 kPa (150 to 300 Torr), corresponding to the range over which the lifetime was prolonged. Fig. 11 represents a lifetime-to-pressure characteristic of the display panel, as shown in Figs. 6A and 6B having an Al cathode and Ne - Xe (10%) which was driven at the constant current mode under conditions of D = 1 and I = 100 μ A then converted into the lifetime with D = 1/60. Furthermore, when both of the ordinate and abscissa of the graph shown in Fig. 11 are changed to a logarithmic scale, a graph as shown in Fig. 12 was obtained.

In Fig. 13, there is shown a lifetime-to-pressure characteristic using a He - Xe (10%) - Kr (10%) filling gas (namely, a filling gas composed of a He gas with partial pressure of 80%, a Xe gas with partial pressure of 10%, and a Kr gas with partial pressure of 10%). More precisely Fig. 13 represents a lifetime-to-pressure characteristic of a display panel having an Al cathode and He - Xe (10%) - Kr (10%) filling gas driven in the constant current mode under condition of D = 1 and I = 100 μ A.

Fig. 14 indicates a lifetime-to-pressure characteristic of a display panel as shown in Figs. 6A and 6B having an Al cathode and a Ne - Xe (10%) - Kr (10%) filling gas when driven in the constant current mode under conditions of D = 1 and I = 100 μ A. It should be noted that the lifetimes shown in Figs. 12 to 14 have

been converted into those of $D = 1/60$. It could be recognized from the gradients of the curves from Fig. 12 to Fig. 14 that the lifetime of the panel is substantially proportional to between p^5 and p^6 ("p" indicates total pressure of filling gas).

Figs. 15 to 42 show further experimental data.

Fig. 15 indicates a lifetime-to-Xe-partial pressure ratio characteristic measured when the display panel having an Al cathode and He-Xe filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D = 1$ and $I = 100 \mu A$. In Fig. 15, there are shown the characteristics obtained under such conditions that the total pressure "p" of the filling gas is used as the parameter, and the total pressure "P" is selected to be 60 kPa (450 Torr), 40 kPa (300 Torr), and 27 kPa (200 Torr). It should be noted that the lifetimes of the display panel in Fig. 15 have been converted into the lifetimes under $D = 1/60$.

Fig. 16 shows a lifetime-to-Xe-partial pressure ratio characteristic measured when the display panel having the Al cathode, Ne-Xe filling gas, and total pressure $P = 27$ kPa (200 Torr), as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D = 1$ and $I = 100 \mu A$. Note that the lifetimes shown in Fig. 15 have been converted into those of $D = 1/60$.

Fig. 17 indicates a lifetime-to-Kr-partial pressure ratio characteristic measured when the display panel having the Al cathode and He-Xe (10%) - Kr filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D = 1$ and $I = 100 \mu A$. In Fig. 17, there are shown the characteristics obtained under such conditions that the total pressure "p" of the filling gas is used as the parameter, and the total pressure "P" is selected to be 27 kPa (200 Torr), 47 kPa (350 Torr), and 60 kPa (450 Torr). It should be noted that the lifetimes of the display panel in Fig. 17 have been converted into the lifetimes under $D = 1/60$.

Fig. 18 indicates a lifetime-to-Kr-partial pressure ratio characteristic measured when the display panel having the Al cathode and Ne-Xe (10%) - Kr filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D = 1$ and $I = 100 \mu A$. In Fig. 18, there are shown the characteristics obtained under such conditions that the total pressure "p" of the filling gas is used as the parameter, and the total pressure "P" is selected to be 20 kPa (150 Torr), 27 kPa (200 Torr), and 40 kPa (300 Torr). It should be noted that the lifetimes of the display panel in Fig. 18 have been converted into the lifetimes under $D = 1/60$.

Fig. 19 shows a lifetime-to-Kr-partial pressure ratio characteristic measured when the display panel having the Al cathode, He-Xe-Kr filling gas, and total pressure 27 kPa ($P = 200$ Torr), as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D = 1$ and $I = 100 \mu A$. In Fig. 19, there are shown the characteristics measured under such conditions that the partial pressure ratio of the Xe gas is used as a parameter, and this partial pressure ratio is selected to be 10%, 20% and 40%. Note that the lifetimes shown in Fig. 19 have been converted into those of $D = 1/60$.

Fig. 20 indicates a lifetime-to-Kr-partial pressure ratio characteristic measured when the display panel having the Al cathode, Ne-Xe-Kr filling gas, and 27 kPa ($P = 200$ Torr), as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D = 1$ and $I = 100 \mu A$. In Fig. 20, there are shown characteristics when the partial pressure ratio of the Xe gas is used as a parameter, and this partial pressure is selected to be 4%, 6%, 10%, 20% and 40%. It should be noted that the lifetimes of the display panel in Fig. 20 have been converted into the lifetimes under $D = 1/60$.

Fig. 21 indicates a lifetime-to-current characteristic measured when the display panel having the Al cathode and He-Xe (10%) filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under condition of $D = 1$. In Fig. 21, there are shown the characteristics obtained under such conditions that the total pressure "p" of the filling gas is used as the parameter, and the total pressure "P" is selected to be 47 kPa (350 Torr), 40 kPa (300 Torr), 33 kPa (250 Torr) and 27 kPa (200 Torr). It should be noted that the lifetimes of the display panel in Fig. 21 have been converted into the lifetimes under $D = 1/60$.

Fig. 22 shows a lifetime-to-current characteristic measured when the display panel having the Al cathode, Ne-Xe (10%) filling gas, and total pressure $P = 27$ kPa (200 Torr), as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D = 1$. Note that the lifetimes shown in Fig. 22 have been converted into those of $D = 1/60$.

Fig. 23 indicates light-emission efficiency-to-current a characteristic measured when the display panel having the Al cathode and He-Xe (10%) filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D = 1/60$. In Fig. 23, there are shown the characteristics obtained under such conditions that the total pressure "p" of the filling gas is used as the parameter, and the total pressure "P" is selected to be 60 kPa (450 Torr), 47 kPa (350 Torr), 40 kPa (300 Torr), 33 kPa (250 Torr), 27 kPa (200 Torr), and 20 kPa (150 Torr).

Fig. 24 indicates light-emission efficiency-to 20 current a characteristic measured when the display panel having the Al cathode and Ne-Xe (10%) filling gas, as shown in Figs. 6A and 6B, is driven in the

constant current mode under condition of $D = 1/60$. In Fig. 24, there are shown the characteristics obtained under such conditions that the total pressure "p", of the filling gas is used as the parameter, and the total pressure "P" is selected to be 20 kPa (150 Torr), 27 kPa (200 Torr), 33 kPa (250 Torr), and 47 kPa (350 Torr).

Fig. 25 indicates a light-emission efficiency-to-current characteristic measured when the display panel having the Al cathode, Ne-Xe filling gas, and $P = 27$ kPa (200 Torr), as shown in Figs. 6A and 6B, is driven in the constant current mode under condition of $D = 1/60$. In Fig. 25, there are shown characteristics obtained when the partial pressure ratio of the Xe gas is used as the parameter, and this partial pressure ratio is selected to be 4%, 10%, 20% and 40%.

Fig. 26 represents a light-emission efficiency-to-current characteristic measured when the display panel having the Al cathode, Ne-Xe (10%) - Kr filling gas, and $p = 27$ kPa (200 Torr), as shown in Figs. 6A and 6B, is driven in the constant current mode under condition of $D = 1/60$. In Fig. 26, there are shown characteristic obtained when the partial pressure ratio of the Kr gas is used as the parameter, and this partial pressure is selected to be 0%, 1%, 4% 10% and 45%.

Fig. 27 represents a luminance-to-current characteristic measured when the display panel having the Al cathode, and He-Xe (10%) filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under condition of $D = 1/60$. In Fig. 27, there are shown the characteristics obtained under such conditions that the total pressure "p" of the filling gas is used as the parameter, and the total pressure "p" is selected to be 60 kPa (450 Torr), 40 kPa (300 Torr), 33 kPa (250 Torr), and 27 kPa (200 Torr).

Fig. 28 represents a luminance-to-current characteristic measured when the display panel having the Al cathode, and Ne-Xe (10%) filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under condition of $D = 1/60$. In Fig. 28, there are shown the characteristics obtained under such conditions that the total pressure "p", of the filling gas is used as the parameter, and the total pressure "p" is selected to be 20 kPa (150 Torr), 27 kPa (200 Torr), 33 kPa (250 Torr) and 47 kPa (350 Torr).

Fig. 29 indicates a luminance-to-current characteristic measured when the display panel having the Al cathode and He-Xe filling gas, and $P = 40$ kPa (300 Torr), as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D = 1/60$. In Fig. 29, there are shown characteristics obtained when the partial pressure ratio of the Xe gas is used as the parameter, and this partial pressure is selected to be 20%, 10% and 4%.

Fig. 30 represents a luminance-to-current characteristic measured when the display panel having the Al cathode, Ne-Xe filling gas, and $p = 27$ kPa (200 Torr), as shown in Figs. 6A and 6B, is driven in the constant current mode under condition of $D = 1/60$. In Fig. 30, there are shown characteristics obtained when the partial pressure ratio of the Xe gas is used as the parameter, and this partial pressure is selected to be 40%, 20%, 10% and 4%.

Fig. 31 indicates a voltage between electrodes (voltage between anode and cathode of discharge cell)-to-current characteristic measured when the display panel having the Al cathode and He-Xe (10%) filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under condition of $D = 1$. In Fig. 31, there are shown the characteristics obtained under such conditions that the total pressure "p", of the filling gas is used as the parameter, and the total pressure "P" is selected to be 20, 27, 33, 40, 47 and 60 kPa (150, 200, 250, 300, 350 and 450 Torr).

Fig. 32 indicates a voltage between electrodes-to-current characteristic measured when the display panel having the Al cathode and Ne-Xe (10%) filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D = 1$. In Fig. 32, there are shown the characteristics obtained under such conditions that the total pressure "p" of the filling gas is used as the parameter, and the total pressure "P", is selected to be 20, 27, 33, and 47 kPa (150, 200, 250 and 350 Torr).

Fig. 33 represents a voltage across electrodes-to-current characteristic measured when the display panel having the Al cathode, Ne-Xe filling gas, and $p = 27$ kPa (200 Torr), as shown in the constant current mode under condition of $D = 1$. In Fig. 33, there are shown characteristic obtained when the partial pressure ratio of the Xe gas is used as the parameter, and this partial pressure ratio is selected to be 40%, 20%, 10% and 4%.

Fig. 34 indicates a voltage between electrodes-to-pressure (total pressure of filling gas) characteristic measured when the display panel having the Al cathode and He-Xe filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D = 1$ and $I = 60 \mu A$. In Fig. 34, there are shown characteristics obtained when the partial pressure ratio of the Xe gas is used as the parameter, and this partial pressure ratio is selected to be 10% and 4%.

Fig. 35 indicates a voltage between electrodes-to-pressure characteristic measured when the display panel having the Al cathode and Ne-Xe (10%) 10 filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D = 1$ and $I = 60 \mu A$.

Fig. 36 indicates a minimum sustaining discharge current-to-pressure characteristic measured 15 when the display panel having the Al cathode and He-Xe (4%) filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under condition of $D=1$.

Fig. 37 indicates a minimum sustain discharge current-to-pressure characteristic measured when the 5 display panel having the Al cathode and Ne-Xe (10%) filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under condition of $D=1$.

Fig. 38 indicates a light-emission efficiency-to-pressure characteristic measured when the display panel having the Al cathode and He-Xe filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D=1/60$ and $I=60 \mu A$. In Fig. 38, there are shown characteristics obtained when 10 the partial pressure ratio of the Xe gas is used as the parameter, and this partial pressure ratio is selected to be 20%, 10% and 4%.

Fig. 39 indicates a light-emission efficiency-to-Xe-partial pressure ratio characteristic measured when the display panel having the Al cathode and He-Xe filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D=1/60$ and $I=60 \mu A$. In Fig. 39, there are shown the 15 characteristics obtained under such conditions that the total pressure "p" of the filling gas is used as the parameter, and the total pressure "P" is selected to be 60 kPa (450 Torr), 47 kPa (350 Torr), 40 kPa (300 Torr) and 27 kPa (200 Torr).

Fig. 40 indicates a luminance-to-Kr-partial pressure ratio characteristic of the auxiliary discharge cell measured when only this auxiliary discharge cell of the display panel having the Al cathode, Ne-Xe-Kr filling 20 gas and $P=27 \text{ kPa}$ (200 Torr), as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D=1/60$ and $I=100 \mu A$. In Fig. 40, there are shown characteristics obtained when the partial pressure ratio of the Xe gas is used as the parameter, and this partial pressure ratio is selected to be 4%, 10%, 20% and 40%. In other words, Fig. 40 represents how to change luminance of visible Ne light in response to variations in the Kr partial pressure when only the auxiliary discharge cell of the display panel 25 is discharged.

Fig. 41 represents a luminance-to-Xe-partial pressure ratio characteristic of the auxiliary discharge cell measured when only the auxiliary discharge cell of the display panel having the Al cathode, Ne-Xe-Kr filling gas, and $p=27 \text{ kPa}$ (200 Torr), as shown in Figs. 6A and 6B, is driven in the constant current mode under condition of $D=1/60$ and $I=100 \mu A$. In Fig. 41, there are shown characteristics obtained when the partial 30 pressure ratio of the Kr gas is used as the parameter, and this partial pressure is selected to be 0%, 4%, 10% and 40%. In other words, Fig. 41 indicates how to change luminance of visible Ne light in response to the Kr-partial pressure ratio when only the auxiliary discharge cell of the above-described display panel is discharged.

It is understandable from Figs. 40 and 41 that if the partial pressure ratio of the Ne gas is less than 35 80%, the light emission of the visible Ne light is lowered.

Fig. 42 represents a luminance-to-pressure characteristic of the auxiliary discharge cell measured when only the auxiliary discharge cells of the display panel having the Al cathode and Ne-Xe (10%) - Kr (10%) filling gas, as shown in Figs. 6A and 6B, is driven in the constant current mode under conditions of $D=1/60$ and $I=100 \mu A$. That is to say, Fig. 42, represents how to change luminance of visible Ne light in response 40 to variations in the total pressure "p", when only the auxiliary discharge cell of the display panel is discharged.

It should be noted that the visible Ne light is contained in the above-described measurements of the luminance and the light-emission efficiency when Ne gas is contained in the filling gas.

It could be understood from Figs. 10, 13, 15, 17, 19 and 21 that the lifetime "T" of the display panel, 45 shown in Figs. 6A and 6B, into which either He-Xe gas, or He-Xe-Kr gas has been filled, may be approximated by the following equation in case of $D=1/60$:

$$T = \{1 + 700xk^2 / (p/200)^4\} 7 \cdot 10^{-8} xp^5 (60/I)^2 [\text{hour}] \quad (1)$$

50 where symbol "x" indicates a partial pressure ratio of Xe gas, symbol "k" denotes a partial pressure ratio of Kr gas, symbol "p" shows total pressure (133 Pa or 1 Torr) of filling gas and symbol "I" is a current value (μA).

When He-Xe gas is used, the following equation is obtained by substituting $k=0$ into the above-described equation (1):

$$55 \quad T = 7 \cdot 10^{-8} xp^5 (60/I)^2 [\text{hour}] \quad (2)$$

Comparisons between the lifetime values calculated by these approximate expressions and the actually

measured lifetime values shown in tables 1 and 2. It can be seen from tables 1 and 2 that equations (1) and (2) constitute a relatively better evaluating method. Note that table 1 indicates the comparison results under $I = 60 \mu A$, whereas table 2 shows the comparison results under $I = 100 \mu A$.

Table 1

| He-Xe | | | | |
|-------------------------|-------------------------------------|-------------------------------------|---------------------|---------------------|
| p [Torr] (x 133 kPa) | x (partial pressure ratio) | k (partial pressure ratio) | Lifetime [hrs.] | |
| | | | Experiment value | Calculated value |
| 250 | 0.1 | 0 | 7000 | 6800 |
| 300 | 0.04 | 0 | 5500 | 6800 |
| 300 | 0.1 | 0 | 22000 | 17000 |
| 300 | 0.2 | 0 | 42500 | 34000 |
| 350 | 0.1 | 0 | 34000 | 36800 |
| 450 | 0.04 | 0 | 31200 | 51700 |

$I = 60 [\mu A]$

Table 2

He-Xe, He-Xe-Kr

| p [Torr] (x133 Pa) | x (partial pressure ratio) | k (partial pressure ratio) | Lifetime [hrs.] | |
|-----------------------|-------------------------------------|-------------------------------------|---------------------|---------------------|
| | | | Experiment value | Calculated value |
| 200 | 0.1 | 0.1 | 1100 | 1370 |
| | | 0.4 | 9400 | 9840 |
| | 0.2 | 0.2 | 14400 | 10600 |
| | 0.4 | 0.1 | 15000 | 12300 |
| 250 | 0.1 | 0 | 7000 | 6800 |
| 300 | 0.04 | 0 | 5500 | 6800 |
| | 0.1 | 0 | 22000 | 17000 |
| | 0.2 | 0 | 42500 | 34000 |
| 350 | 0.1 | 0 | 34000 | 36800 |
| | | 0.1 | 17300 | 13300 |
| 450 | 0.04 | 0 | 31200 | 51700 |
| | 0.1 | 0.1 | 44000 | 46600 |

$$I = 100 [\mu A]$$

To achieve a lifetime "T" of the display panel, shown in Figs. 6A and 6B, filled with either He-Xe gas, or He-Xe-Kr gas and normally operated under $I = 60 \mu A$ of at least 10,000 hours, using equation (1), the following condition must be satisfied:

$$\{1 + 700xk^2/(p/200)^4\} xp^5 \geq 1.4 \cdot 10^{11} \quad (3)$$

When He-Xe gas is used, the following condition is obtained by substituting $k=0$ into the above-described condition (3):

$$xp^5 \geq 1.4 \cdot 10^{11} \quad (4)$$

It can also be seen from Figs. 12, 14, 15, 16, 18, 20 and 22 that the lifetime "T" of the display panel filled with either Ne-Xe gas or Ne-Xe-Kr gas, as shown in Figs. 6A and 6B, is approximated by the following formula in case of $D = 1/60$:

$$T = \max\{80xk(1-3.3x), 1\} 2.7 \cdot 10^{-7} xp^5 (100/I)^3 [\text{hour}] \quad (5)$$

where symbol "x" indicates a partial pressure ratio of Xe gas, symbol "k" denotes a partial pressure ratio of Kr gas, symbol "p" shows total pressure (133 Pa or 1 Torr), and symbol "I" is a current value (μA).

Furthermore, when Ne-Xe filling gas is used, the following formula is obtained by substituting $k=0$ into formula (5):

$$T = 2.7 \cdot 10^{-7} xp^5 (100/I)^3 [\text{hour}] \quad (6)$$

Comparison results between the lifetime values calculated by these approximate expressions and the

actually measured lifetime values are shown in Table 3. It can be seen that the above-described formulae (5) and (6) constitute a relatively better evaluating method.

Table 3

Ne-Xe, Ne-Xe-Kr

| P [Torr] (133 kPa) | x (partial pressure ratio) | k (partial pressure ratio) | I [μ A] | Lifetime [hrs.] | |
|--------------------------|-------------------------------------|-------------------------------------|--------------|---------------------|---------------------|
| | | | | Experiment value | Calculated value |
| 150 | 0.1 | 0 | 100 | 1450 | 2050 |
| | | 0 | 150 | 620 | 610 |
| 200 | 0.04 | 0 | 100 | 3500 | 3460 |
| | | 0.1 | 100 | 2500 | 3460 |
| | | 0.4 | 100 | 3000 | 3840 |
| | 0.06 | 0.4 | 100 | 10000 | 7980 |
| | 0.1 | 0 | 60 | 34000 | 40000 |
| | | | 100 | 8400 | 8640 |
| | | | 150 | 3400 | 2560 |
| | | | 200 | 1050 | 1080 |
| | | 0.04 | 100 | 5600 | 8640 |
| | | 0.1 | 100 | 9000 | 8640 |
| | | 0.4 | 100 | 20000 | 18400 |
| | 0.2 | 0 | 100 | 14500 | 17300 |
| | | 0.1 | 100 | 15000 | 17300 |
| | | 0.4 | 100 | 30000 | 36800 |
| | 0.4 | 0 | 100 | 40000 | 34600 |
| | | 0.1 | 100 | 40500 | 34600 |
| 250 | 0.1 | 0 | 100 | 38000 | 26400 |
| 300 | 0.1 | 0.1 | 100 | 76000 | 65000 |
| 350 | 0.1 | 0 | 100 | 130000 | 142000 |

To achieve a lifetime "T", of the display panel, shown in Fig. 6A and 6B, filled with either Ne-Xe gas, or Ne-Xe-Kr gas and operated at $I=60\mu$ A of at least 10,000 hours using formula (5), the following condition must be satisfied:

$$\max\{80xk(1-3.3x), 1\} \cdot xp^5 \geq 8.0 \cdot 10^9 \quad (7)$$

When Ne-xe gas is used, the following formula is obtained by substituting $k=0$ into formula (7):

$$xp^5 \geq 8.0 \cdot 10^9 \quad (8)$$

The value of the discharge current must be considered as a discharge current density. To this end, an active cathode area must be considered. When the interval between the cathode and the anode of the display panel as shown in Figs. 6A and 6B is not constant, the places actually operating as the normal glow-discharge regions are generally different from each other, depending upon the pd-product. In this case, the interval is set to be 1.2 times the minimum distance "d". In order to make this interval operate as a cathode a relatively high sustain voltage, e.g. 20 V, is required. With such a high sustain voltage the discharge occurring at the place of the minimum distance "d" is an abnormal glow discharge, and sputtering is rapidly increased. This may also be seen from Figs. 10, 12, 31 and 32. As shown in Fig. 57, in case of the display panel shown in Figs. 6A and 6B, abnormal glow-discharge occurs over about 2/3 area of the entire cathode area. In this drawing, assuming now that an anode is one point and $dm = 1.2d$, an actual cathode area "S" is obtained by:

$$\begin{aligned} S &= 2\ell m \times W = 2\sqrt{dm^2 - d^2} \times W = 2\sqrt{0.44} d \times W \\ &= 1.33 dW = 1.33 \ell W \end{aligned}$$

Accordingly, an overall area "2 ℓ W" becomes approximately 2/3. In this display panel, the active cathode area "S" is equal to 0.04 mm².

Since the active anode area could be defined, current density is calculated, and then the following formula is obtained by modifying formula (1) when He-Xe-Kr filling gas is used:

$$T = \{1 + 700xk^2 / (p/200)^4\} 0.16 xp^5 (S/l)^2 \quad (9)$$

where symbol "S" denotes an active cathode area (mm²).

Similarly, when He-Xe filling gas is used, the following formula is obtained by modifying formula (2):

$$T = 0.16 xp^5 (S/l)^2 \quad (10)$$

Similarly, when Ne-Xe-Kr filling gas is used, the following formula is obtained by modifying formula (5)

$$T = \max\{80xk(1-3.3x), 1\} 4.2 \cdot 10^3 xp^5 (S/l)^3 \quad (11)$$

Similarly, when Ne-Xe filling gas is used in the display panel, the following formula is obtained by modifying formula (6):

$$T = 4.2 \cdot 10^3 xp^5 (S/l)^3 \quad (12)$$

With regard to the upper limit of the total pressure, there is a limitation that the total pressure does not exceed atmospheric pressure (101 kPa, 760 Torr). Considering now that a lower limit pressure value is preferable to achieve a sufficient lifetime of the display panel, and also when pressure "p", is increased, the stable minimum sustain that current is increased, as shown in Figs. 36 and 37, resulting in lowering of the efficiency, the maximum pressure values of the display panel are preferably selected to be 80 kPa (600 Torr) in case of He-Xe and He-Xe-Kr filling gases, and 67 kPa (500 Torr) in case of Ne-Xe and Ne-Xe-Kr filling gases. Also, due to the stable discharge, it is preferable to set: $x \leq 0.5$ and $k \leq 0.5$. As to the discharge distances "d", the pd-product may be preferably selected to be 1 to 10 (1.3 Pa.m, 1 Torr. cm) when He-Xe and He-Xe-Kr filling gases are filled, and 0.5 to 10 (1.3 Pa.m, 1 Torr. cm) when Ne-Xe and Ne-Xe-Kr filling gases are filled. Also, taking account of the light-emission efficiency, it is preferable to set: $0.01 \leq x$.

Although a write voltage for a memory drive of a display panel must be higher than a sustain voltage by several tens of Volts, for example, 50 V, such a write voltage may cause a large current flow in this display panel, as apparent from Figs. 31 and 32, thus shortening the lifetime thereof. Therefore, a certain type of current limiting element must be connected in series with the display panel. Normally, since a resistor is employed, this resistor may be connected as shown in Figs. 4A and 4B.

bus line "DAB" is positioned either parallel to "C", or parallel to the write anode bus line (WAB), and since a sustain discharge operation is carried out between the bus line (DAB) and "C". In this case, the display panel is driven only in the pulse memory mode.

Display panels are classified based upon a combination of (1) whether the resistor is connected to the front plate, or the back plate; (2) whether the electrode to which the resistor is connected is an anode, a cathode, or a write electrode; and (3) whether or not an auxiliary discharge is present. These combinations may be conceived as the above-described two examples, or as other examples. If these display panels are combined with other display panels as shown in Figs. 48A to 51B (will be discussed later), display panels with conspicuous characteristics may be obtained.

There are two panel driving methods, i.e., a DC memory drive mode and a pulse memory drive mode. Under normal conditions, the display panels according to the present invention may be driven in either drive mode.

It should be noted that the power consumption of a sustain pulse is small in structure in which the cathode is positioned parallel to a display anode bus line.

Referring now to Figs. 48A to 56B, DC type gas-discharge display panels according to other preferred embodiments of the present invention will be described.

Fig. 48A is a plan view for showing a portion of a DC type gas-discharge display panel according to another preferred embodiment of the present invention, and Fig. 48B is a sectional view of this display panel, taken along a line X_{13} to X_{14} shown in Fig. 48A.

In Figs. 48A and 48B, since the parts denoted by the same symbols as used in Figs. 5A and 5B have the same functions as those of the corresponding parts shown in Figs. 5A and 5B, and also the operations thereof are similar to those of the parts shown in Figs. 5A and 5B, explanations thereof are omitted. The shape of a resistor constituting the feature of this preferred embodiment will now be described. It should be understood that an anode bus line "AB" corresponds to a second conductive line, a cathode "C" corresponds to a first conductive line, and also an anode "A" corresponds to a second discharge electrode in this preferred embodiment.

In Figs. 48A and 48B, a resistive material "RM" is formed in a band shape in such a manner that under one pair of parallel anode bus lines "AB", the size of this resistive material is larger than the size of the anode bus line "AB", and the band-shaped resistive material is positioned over a plurality of discharge cells "DCE" in common to the anode bus line "AB". An anode "A" is formed at substantially the center of two anode bus lines "AB", and a resistor "R" is terminated by this anode together with the anode bus line "AB".

Referring now to Figs. 52A to 52C, conditions on the distances between the adjoining anodes "A" positioned along a direction of the anode bus line "AB" will be described. As shown in Figs. 52A and 52B, if the sizes of the anodes A1 and A2 are 2x2, the distance between the anodes A1 and A2, and the anode bus line "AB" is 1, and the distance between the adjoining anodes A1 and A2 is "m", resistance values of a resistor terminated by the anode A1 and the anode bus line "AB" are calculated if (a) the potential of the adjoining anode A2 is the same as that of the anode bus line "AB" (0V), and (b) the potential of the adjoining anode A2 is equal to that of the anode A1 (1V). The calculated resistance values are shown in Fig. 52C. As a consequence, if the distance "m", is greater than, or equal to 6, it can be seen that the influence of the adjoining anodes A1 and A2 may be reduced below 1%.

The resistance value of thus formed resistor "R" is not adversely influenced by fluctuations appearing in the shape or size of the resistive material "RM". Also, this resistance value is not adversely influenced by the edges or end portions of the resistive material where the thickness of the resistive material RM fluctuates most. As a consequence, a lack of luminous uniformity, or luminous variation of each gas-discharge cell can be reduced without requiring high precision during production.

Furthermore, the adverse influences of the position and dimension of the anode "A" for terminating the resistive material "RM" on the resistance values will now be described more in detail with reference to Figs. 53A to 55B.

In Figs. 53A and 53B, calculated resistance values of the resistor "R" terminated by the anode "A" and the anode bus line "AB" are shown when the anode "A" is vertically shifted toward the anode bus line "AB". As shown in Fig. 53A, when the size of the anode A is 2x2, the distance between the anode "A" and the anode bus line "AB" is 1, and the positional shift thereof is "d" (relative value), variations in the resistance values of the resistor R are shown in Fig. 53B. As a consequence, when the positional shift is 0.1 (corresponding to 10%), the variations in the resistance values are below 1%. Also, as apparent from Figs. 52A to 52C, positional shift parallel to the anode bus line "AB", has no adverse influence to the resistance values at all.

Figs. 54A to 55B represent calculation results with respect to the adverse influences of the sizes of the anode "A" to the resistance values, variations parallel to the anode bus line "AB", and variation perpendicular thereto. As a result, to reduce the variations in the resistance values within, for instance, 1%, precision along the parallel direction to the anode bus line AB should be below 2%, and precision along the direction perpendicular to the anode bus line should be below 1.3%.

The shape of the resistor employed in the discharge display panel according to the present invention is not limited to that shown in Figs. 48A and 48B, but may be such a shape that, for instance, the anode bus line AB is located under the resistive material RM as shown in Figs. 49A and 49B. In this case, as represented in Figs. 49A and 49B, the resistive material RM may be formed in such a manner that this resistive material "RM" extends outside of the anode bus line "AB". However, for example, the resistive material "RM" may extend only to the outer edge or the central portion of the anode bus line "AB" thereon.

Also, as shown in Figs. 50A and 50B, a resistor "R" may be formed by being terminated by a comb-shaped branch anode bus line ABO branched from the anode bus line AB and an anode formed near the center thereof. When a resistive material "RM" is printed in a band shape along a longitudinal direction thereof by way of the thick-film printing operation, this resistive material can be easily made uniform except for the starting and ending portions of the printing operation. There is a particular advantage that there are no particular problems in precision of dimension for formation of an electrode the comb-shaped branch anode bus line ABO and the anode "A" for terminating the resistive material RM are wider than the resistive material RM.

Referring now to Figs. 56A and 56B, the positional precision with respect to the branch anode bus line ABO of the anode A will be explained in the preferred embodiment shown in Figs. 50A and 50B. As shown in Fig. 56A, when a distance between the anode "A" and the branch anode bus line ABO is equal to 1, and also a positional shift is "g", variations in the resistance values of the resistor R caused by the positional shift "g" are represented in Fig. 56B. As a result, when the positional shift is 0.1 (equivalent to 10%), the variations in the resistance values are below 1%.

In the preferred embodiment shown in Figs. 50A and 50B, the anode bus line "AB", may be formed under the resistive material "RM", which is similar to the previous embodiment of Figs. 49A and 49B.

Furthermore, as illustrated in Figs. 51A and 51B, a branch anode bus line ABC may be formed in the shape of a ladder, and an anode "A" positioned adjacent to the bus line may be separate therefrom. In this case, if the positional precision between the anode "A", anode bus line "AB" and branch anode bus line ABC is up to 10% in any direction, then the variations in the resistance values are below 1%. Also, the distance between the adjoining anodes "A" may be shortened, as compared with that of the preferred embodiment shown in Figs. 48A and 48B. In this case, the anode bus line AB may be formed under the resistive material "RM".

Although the resistors are formed at the anode side of the discharge cells in all of the above-described preferred embodiments, these resistors may be, of course, formed at the cathode sides. In which case, the cathode may be formed on the electrode for terminating the resistor. This may be applied to the anode, and material such as Ni which has high resistance against mercury which is usually employed to prolong the lifetime of a gas-discharge display panel may be stacked.

Also, according to the present invention, the above-described inventive idea may be applied not only to the gas-discharge display panel as shown in Figs. 48A and 48B, but also a display panel from which luminous color of a gas discharge such as a Ne gas is directly output from the display panel, and such a display panel without an auxiliary anode.

The present invention is not limited to the display panel having such a structure as shown in Figs. 48A and 48B, but may be applied to display panels in which, for instance, the anode is arranged in an offset relationship with the cathode, namely the anode is not positioned directly opposite to the cathode.

In the embodiments described above the thick-film printing method is employed to manufacture the resistive materials, the bus lines for terminating the resistive materials, and the electrodes, however these parts may be manufactured by various patterning methods, for example, vapour deposition/ photolithography, and chemical etching or lift off.

As the resistive material, the following may be used: RuO_2 , a Nichrome (TM) alloy, tin oxide, Ta_2N , Cr-SiO, ITO, carbon and the like. It is presently preferred to employ a thick film paste made of RuO_2 .

As the electrode material to terminate the resistive material, there are employed Au, Pd, Ag, Al, Ni, Cu, or alloys thereof. Au was found to be best for thick-film 20 printing.

The filling gas utilized in the present invention may be the filling gas as described above.

As the cathode material, Al and Ni and the like may be readily utilized.

If a Ni cathode is solely employed in a display panel, the lifetime of this display panel is shorter than one with an Al cathode. However, if mercury "Hg" is included in the Ni cathode, the lifetime thereof may be

prolonged approximately 100 times longer than the lifetime of the display panel with only the Ni cathode, which becomes longer than that of the display panel with the Al cathode.

All of cathode materials, phosphor materials and filters described regarding the first described embodiment may be utilized in the present embodiment.

5 There are two panel driving methods, i.e., the 10 DC memory drive mode and pulse memory drive mode used for the display panel with the resistor. Both of the drive modes may be utilized in the present invention.

While the present invention has been described with respect to the respective preferred embodiments in detail, the present invention is not restricted to only these preferred embodiments, but may be changed, substituted and modified within the scope of the present invention as defined in the following claims.

Claims

1. A DC type gas-discharge display panel comprising:
 - 15 a plurality of discharge cells (DCE) arranged in a matrix form with a line and column directions;
 - a plurality of resistors (R) provided for each of said discharge cells (DCE), for limiting a discharge current of each of said discharge cells (DCE);
 - a filling gas filling each of said discharge cells (DC);
 - a plurality of first conductive lines (C) elongate in the line direction, each of said first conductive
 - 20 lines (C) being arranged in each of said discharge cells (DCE) in the respective line thereof to constitute a first discharge electrode (C);
 - a plurality of second conductive lines (AB) elongate in said column direction, two adjacent lines of said second conductive lines (AB) being commonly arranged with the respective discharge cells (DCE),
 - wherein, in use, a discharge controlling potential is applied between said first and second
 - 25 conductive lines;
 - a plurality of second discharge electrodes (A) provided substantially centrally between said two adjacent lines of said second conductive lines (AB), which corresponds to each of said discharge cells (DCE), for producing a discharge with said first discharge electrodes (C) in said corresponding discharge cells (DCE); and
 - 30 a plurality of resistive materials (RM) elongate in said column direction, each of said resistive materials (RM) being arranged to bridge the discharge cells (DCE) of a column, and being in contact with both of said two adjacent second conductive lines (AB) and said second electrode (A) of each discharge cell (DCE) of that column; and wherein
 - each of said resistors (R) is formed between said two adjacent second conductive lines (AB) and
 - 35 said second electrode (A) of the respective discharge cell (DCE)
2. A display panel according to Claim 1, wherein said filling gas contains an inert gas mixture, and said inert gas mixture is selected from the group consisting of (1) a first gas mixture consisting of a He gas and a Xe gas, (2) a second gas mixture consisting of a He gas, a Xe gas, and a Kr gas, (3) a third gas
- 40 mixture consisting of a Ne gas and a Xe gas, (4) a fourth gas mixture consisting of a Ne gas, a Xe gas and a Kr gas, and (5) a fifth gas mixture consisting of a Ne gas and a Ar gas.
3. A display panel according to Claim 1 or 2, further comprising:
 - 45 plural pairs of branch conductive lines (ABC) for bridging said two adjacent second conductive lines (A), each pair of said branch conductive lines (ABC) being arranged either side of a second discharge electrodes (A) in the column direction; and wherein
 - each of said resistive materials (RM) is also in contact with each of said branch conductive lines (ABC); and
 - each of said resistors (R) is also terminated by said pair of branch conductive lines (ABC).
 - 50
4. A DC type gas-discharge display panel comprising:
 - a plurality of discharge cells (DCE) arranged in a matrix form in line and column directions;
 - a plurality of resistors (R) provided at each of said discharge cells, for limiting a discharge current
 - of each of said discharge cells (DCE);
 - 55 a filling gas filling each of said discharge cells (DCE);
 - a plurality of first conductive lines (C) elongate in the line direction, each of said first conductive lines (C) being arranged in each of said discharge cells (DCE) in the respective lines to constitute a first discharge electrode (C);

a plurality of second conductive lines (AB) elongate in said column direction, each of said second conductive lines (AB) being commonly arranged with the respective discharge cells (DCE) positioned at the respective columns;

wherein, in use, a discharge controlling potential is applied between said first and second conductive lines;

plural pairs of branch conductive lines (ABO) branched from each of said second conductive lines (AB) along said line direction in a comb shape, each of said pair of branch conductive lines (ABO) being arranged at a position corresponding to each of said discharge cells (DCE);

a plurality of second discharge electrodes (A) provided at substantially centrally between said pairs of branch conductive lines (ABO) for producing a discharge between said first discharge electrodes (C) corresponding to said discharge cells (DCE); and

a plurality of resistive materials (RM) elongate in said column direction, each of said resistive materials (RM) being arranged to bridge the discharge cells (DCE) of said column and being in contact with both of said pair of branch conductive lines (ABO) and said second electrode (A) of said corresponding discharge cells (DCE);

each of said resistors (R) being formed between said pair of branch conductive lines (ABO) and said second electrodes (A) of the respective discharge cell (DCE).

5. A DC type gas-discharge display panel as claimed in Claim 4, wherein said filling gas contains an inert gas mixture, and also said inert gas mixture is selected from the group consisting of (1) a first gas mixture consisting of a He gas and a Xe gas, (2) a second gas mixture consisting of a He gas, a Xe gas, and a Kr gas, (3) a third gas mixture consisting of a Ne gas and a Xe gas, (4) a fourth gas mixture consisting of a Ne gas, a Xe gas and a Kr gas; and (5) a fifth gas mixture consisting of a Ne gas and an Ar gas.

FIG. 1A
PRIOR ART

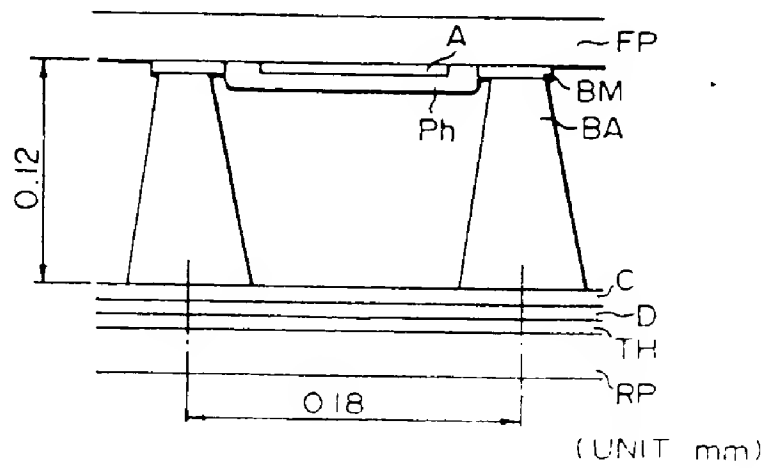


FIG. 1B
PRIOR ART

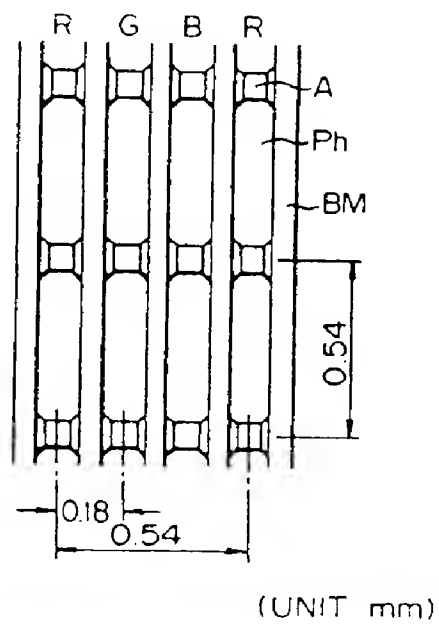


FIG. 2
PRIOR ART

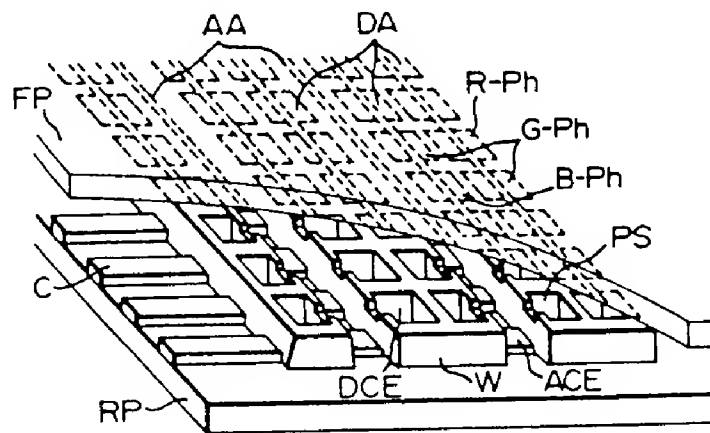


FIG. 3
PRIOR ART

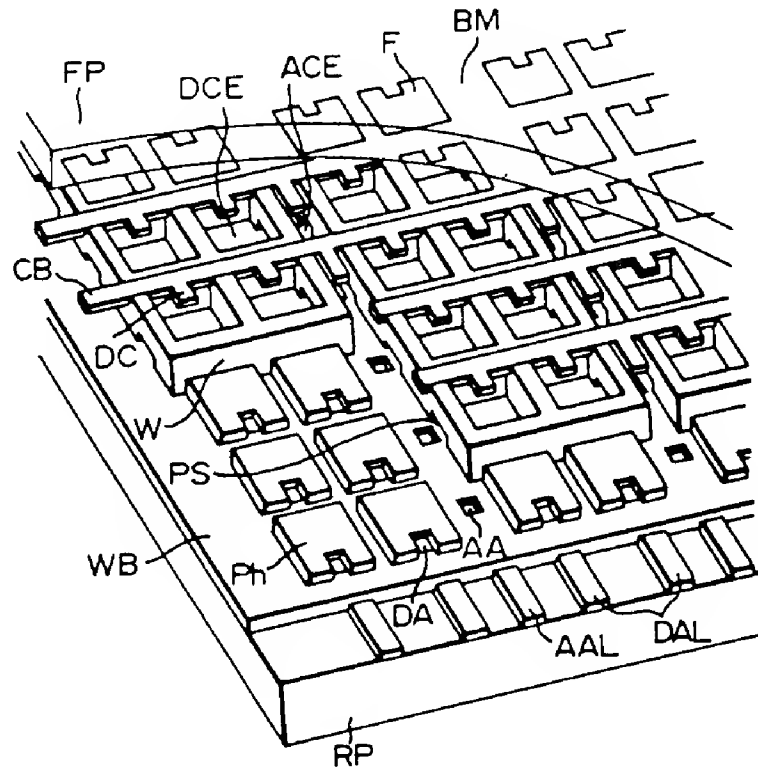


FIG. 4A
PRIOR ART

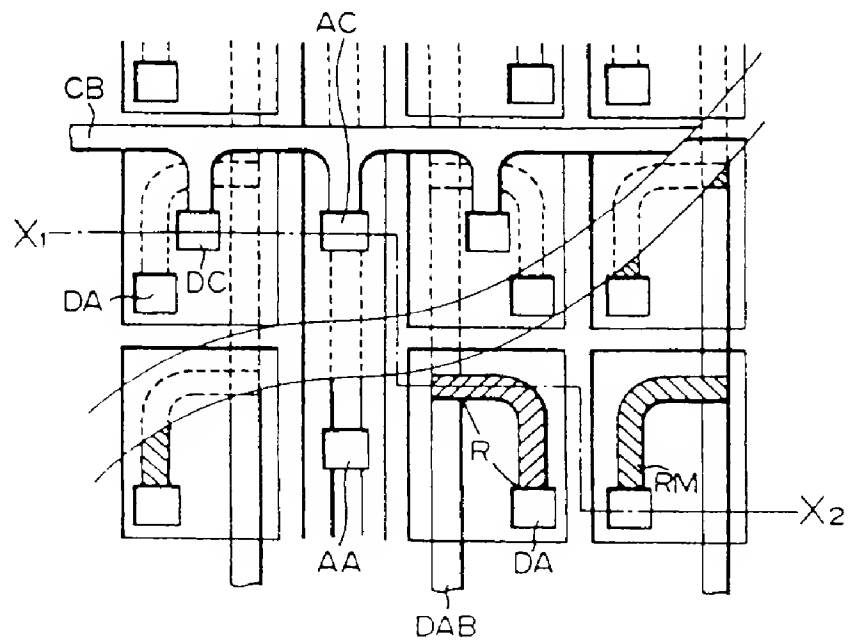


FIG. 4B
PRIOR ART

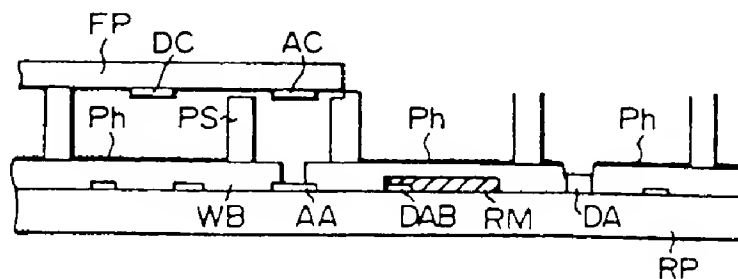


FIG. 5A

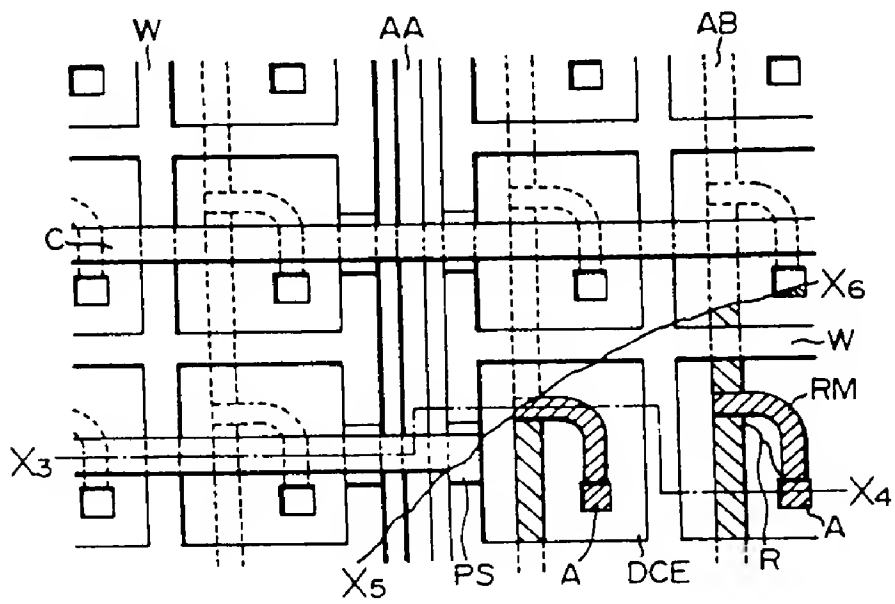


FIG. 5B

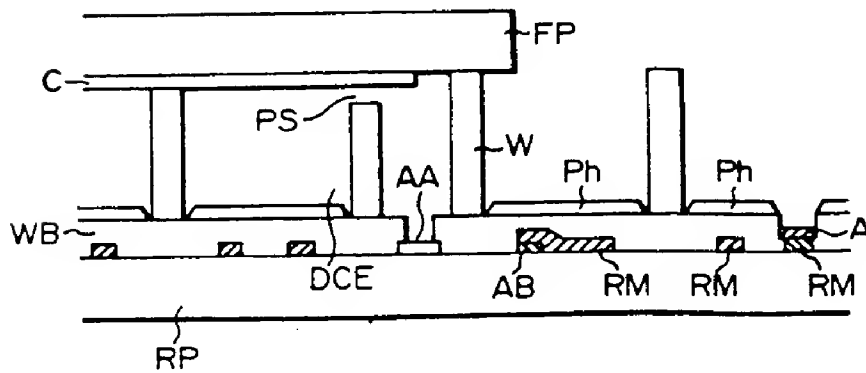


FIG. 6A

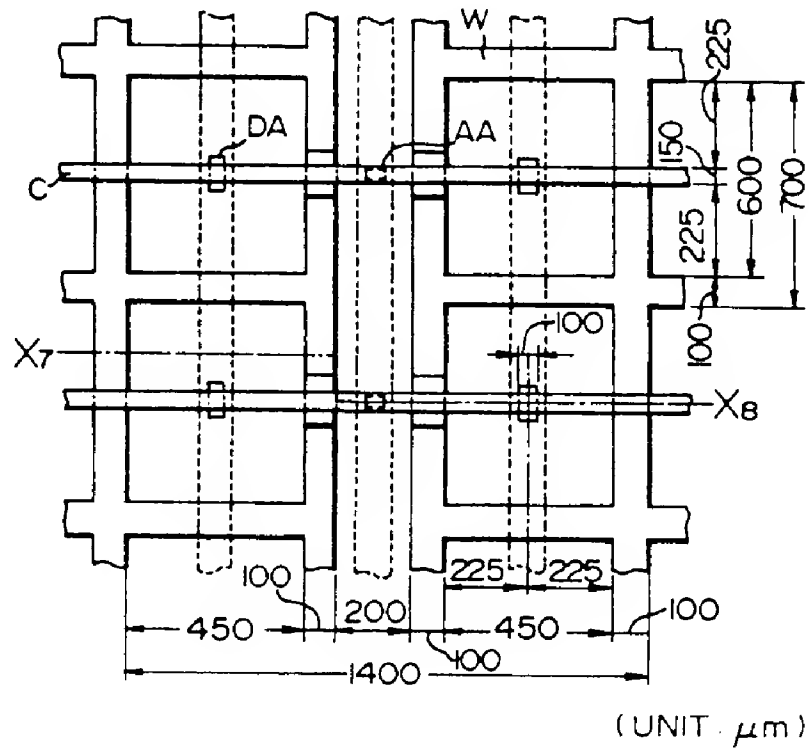


FIG. 6B

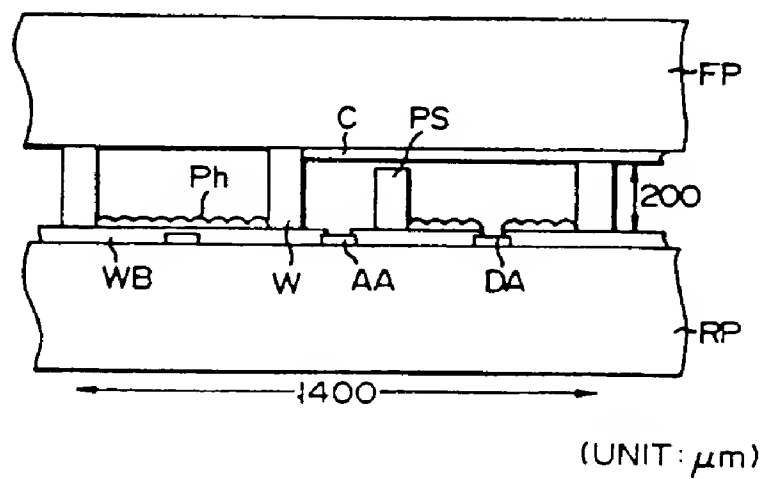


FIG. 7

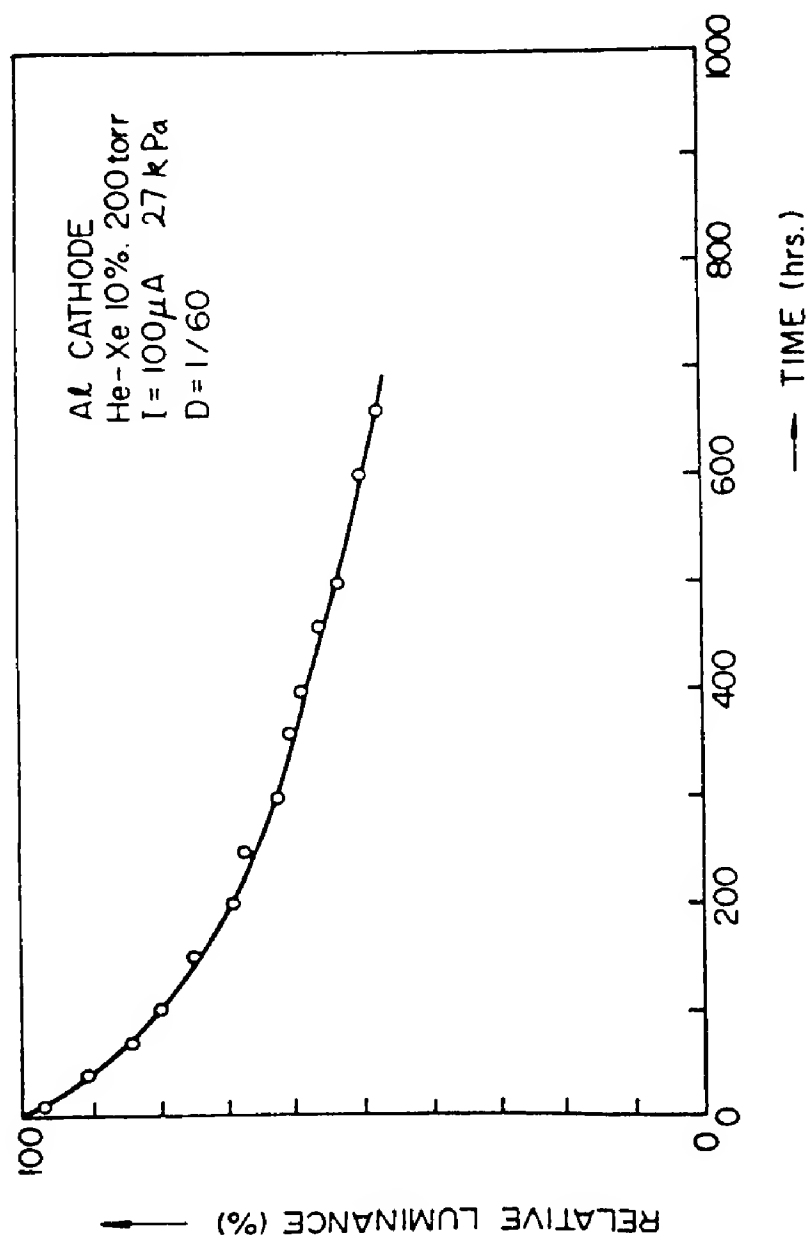


FIG. 8

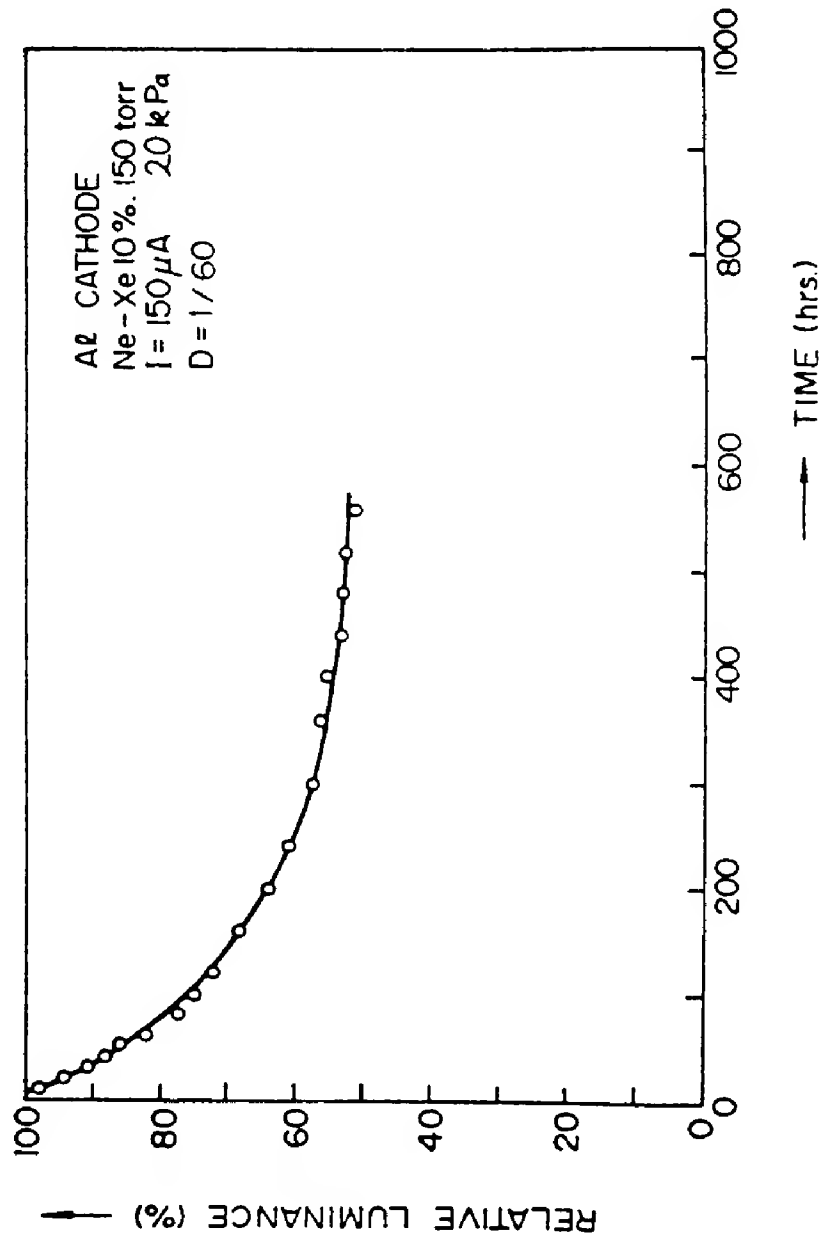


FIG. 9

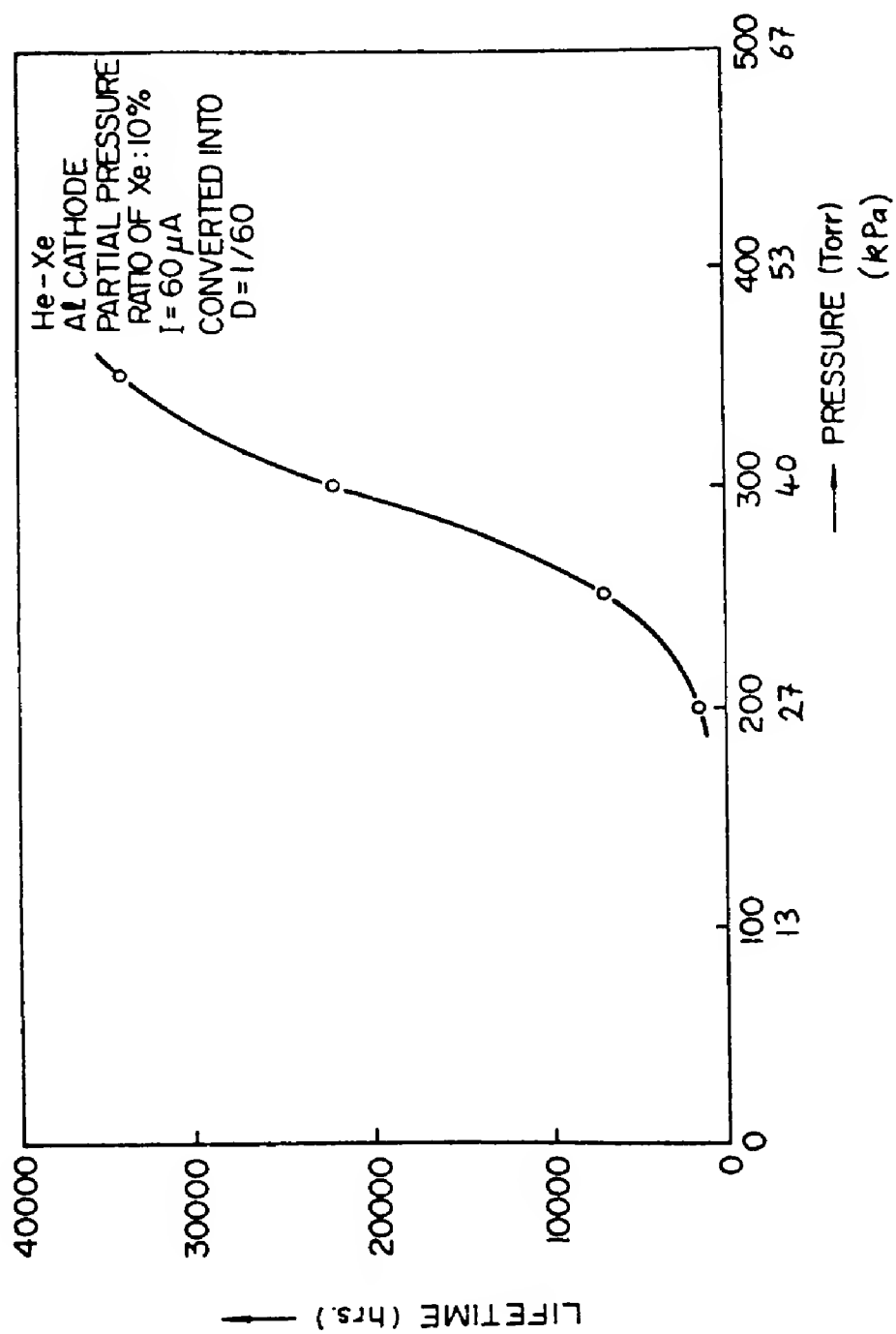


FIG. 10

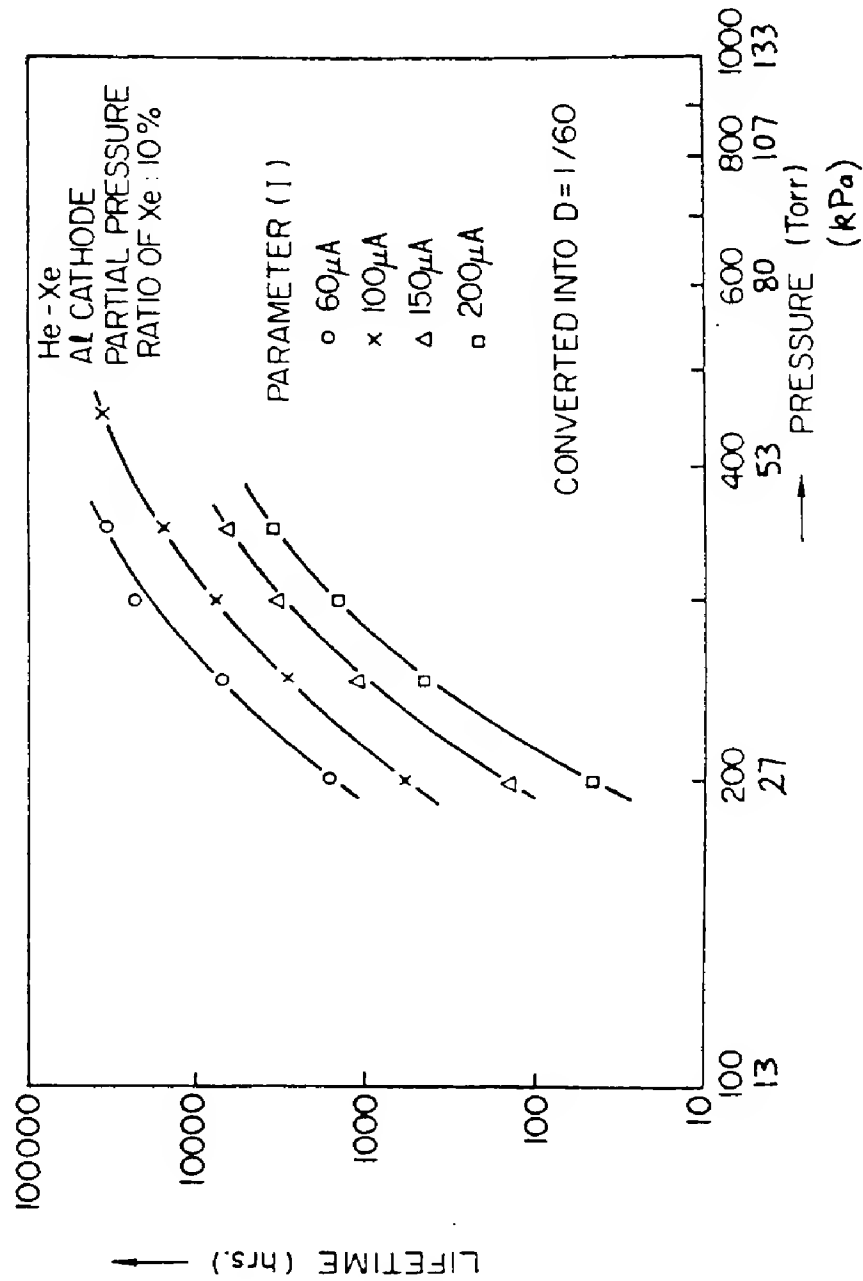


FIG. 11

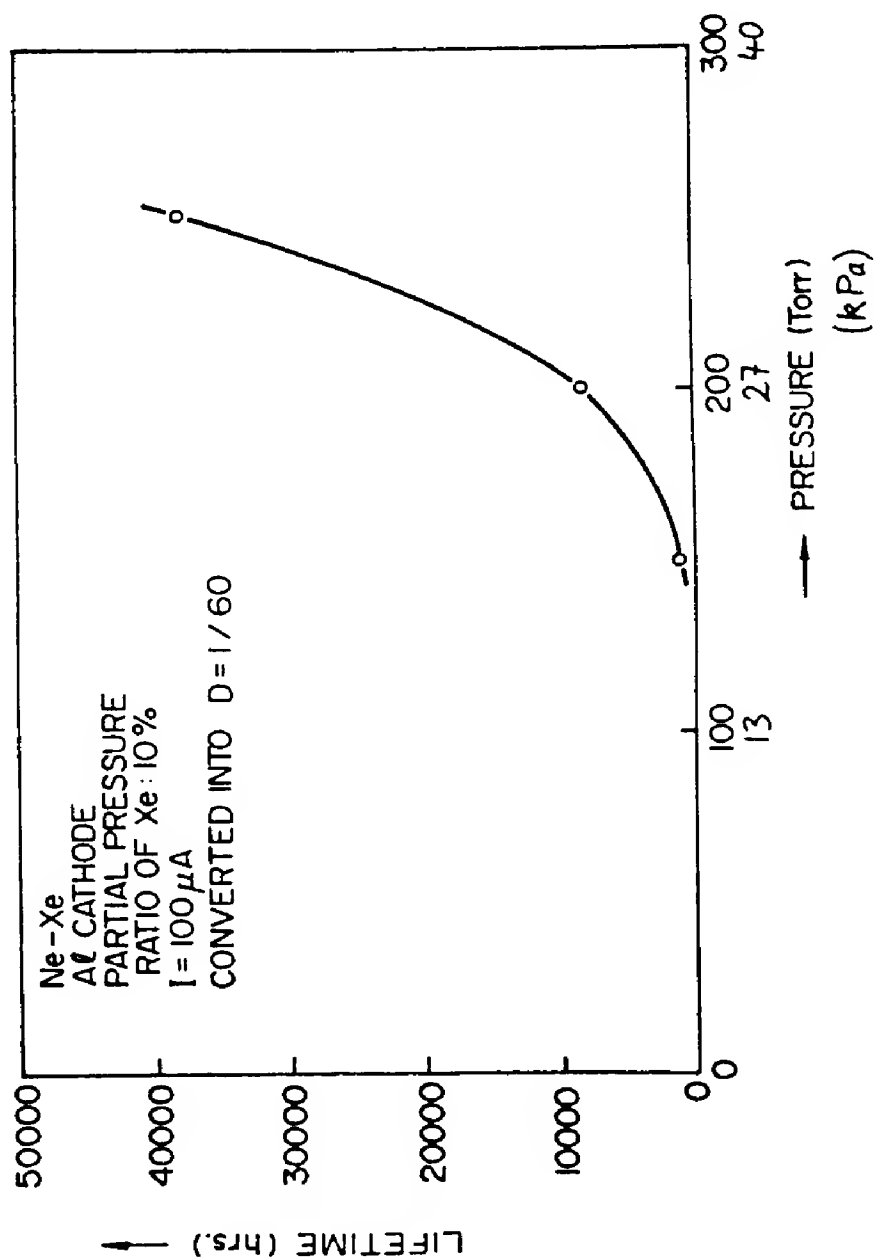


FIG. 12

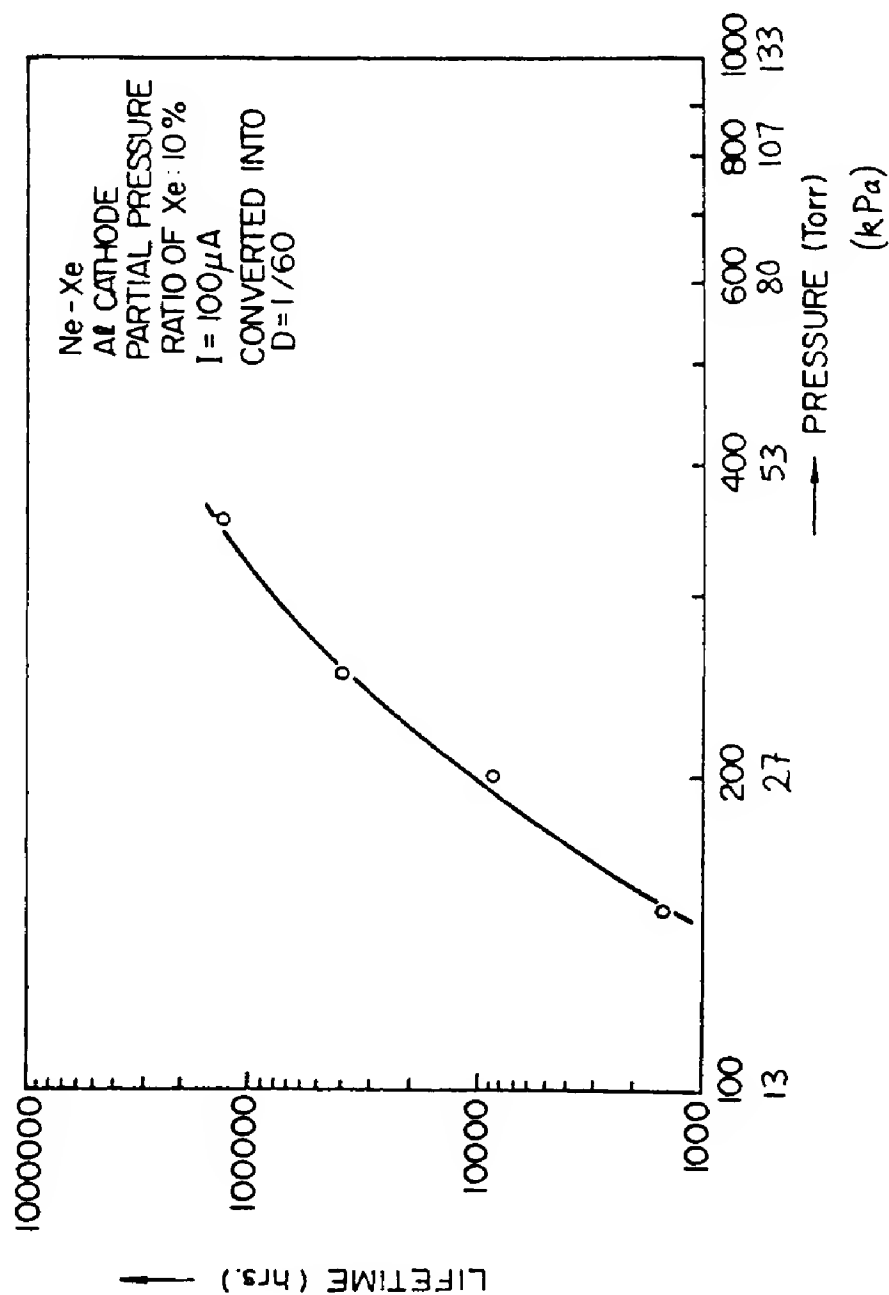


FIG. 13

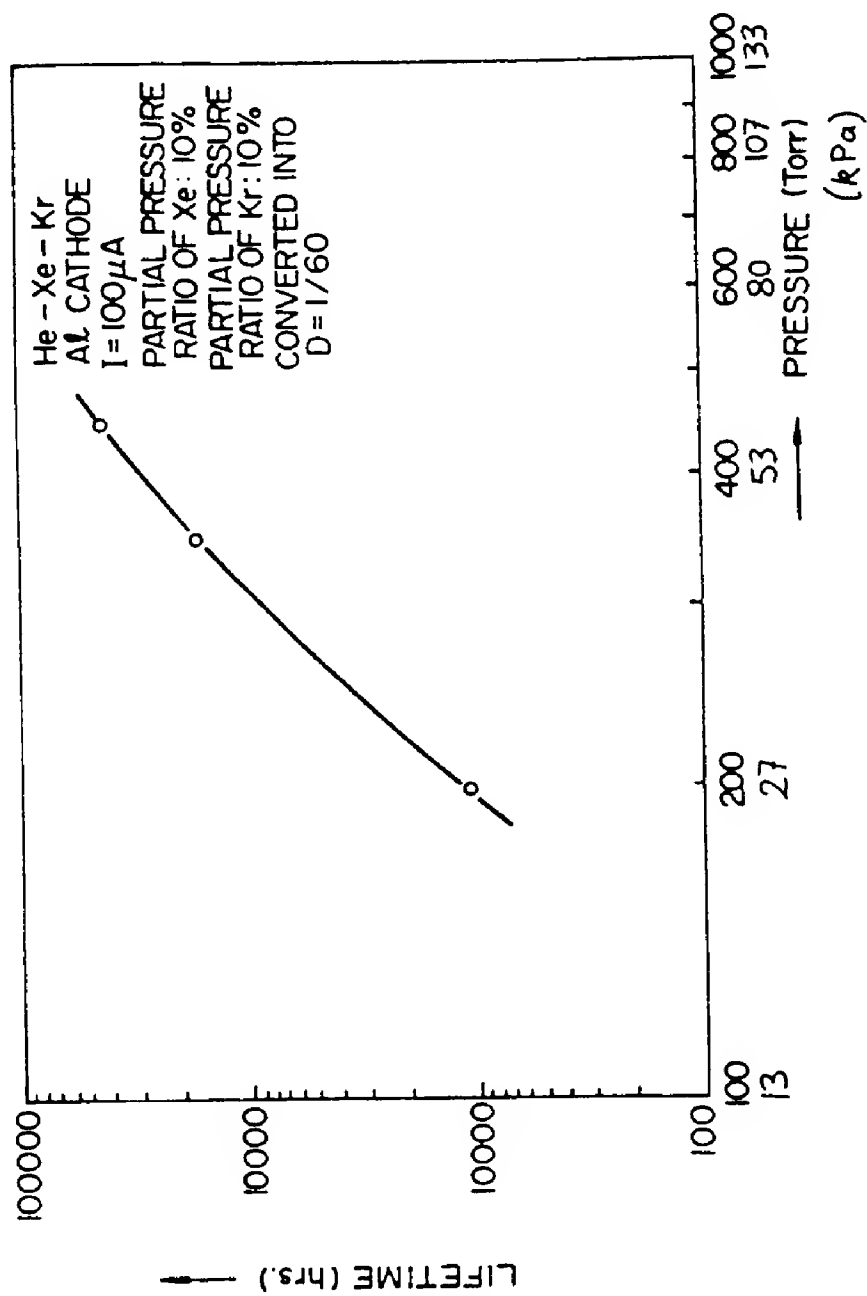


FIG. 14

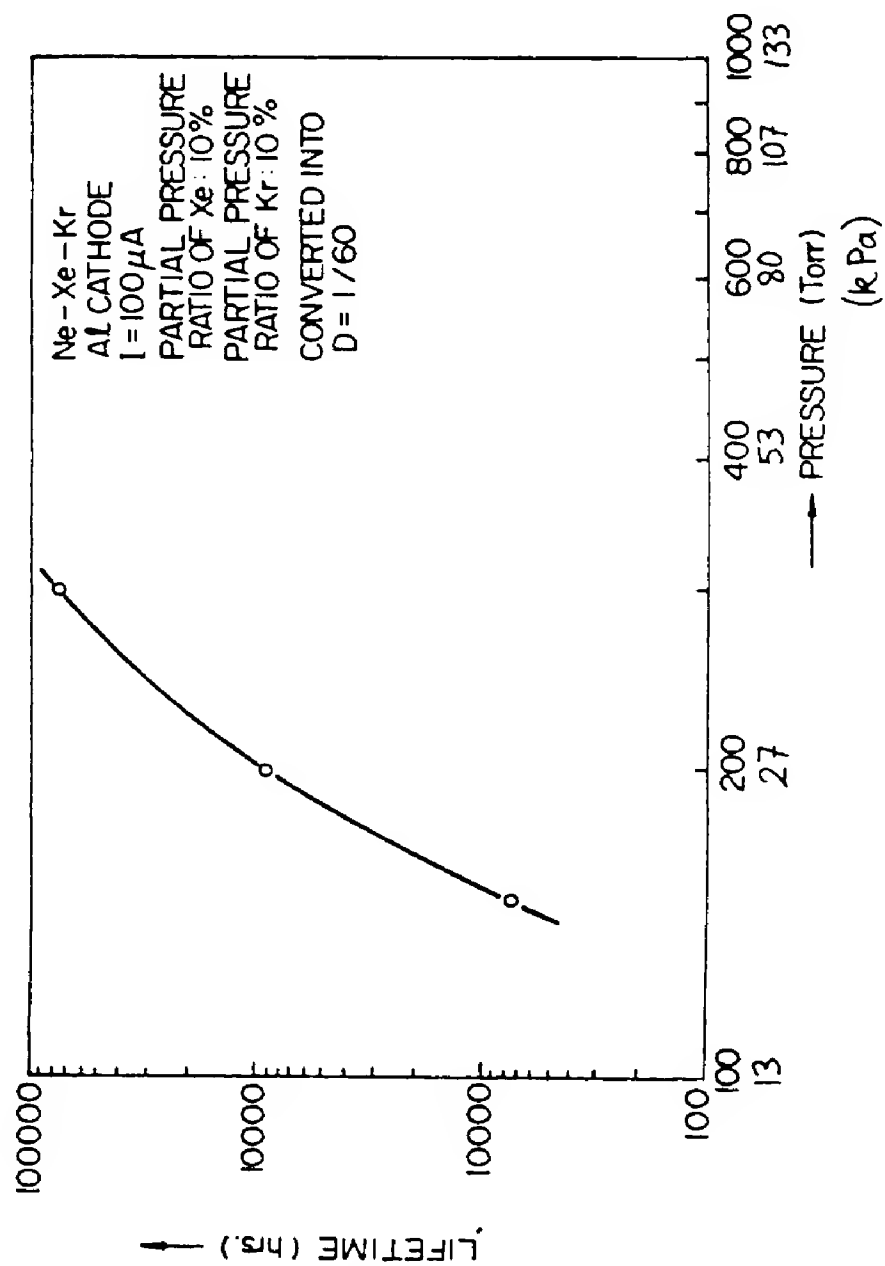


FIG. 15

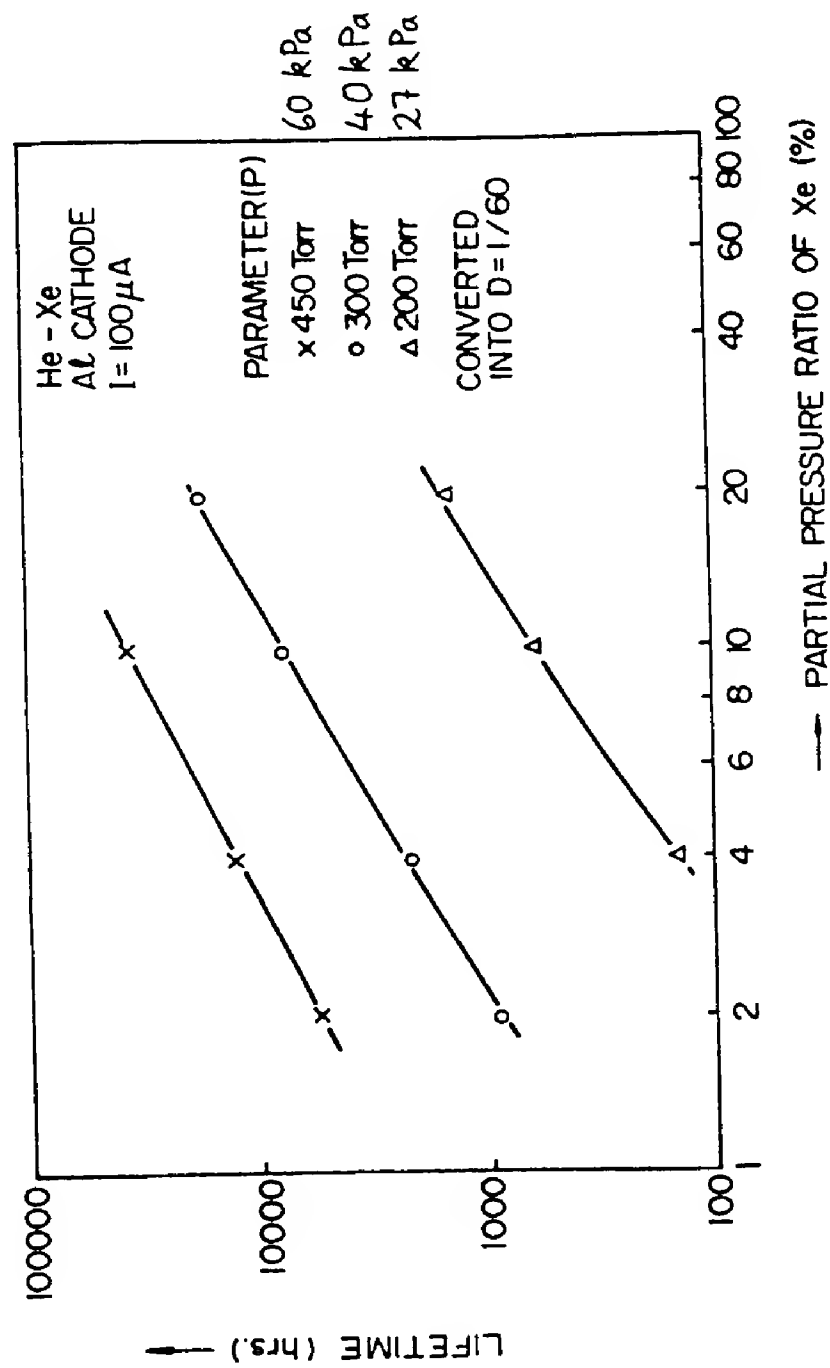


FIG. 16

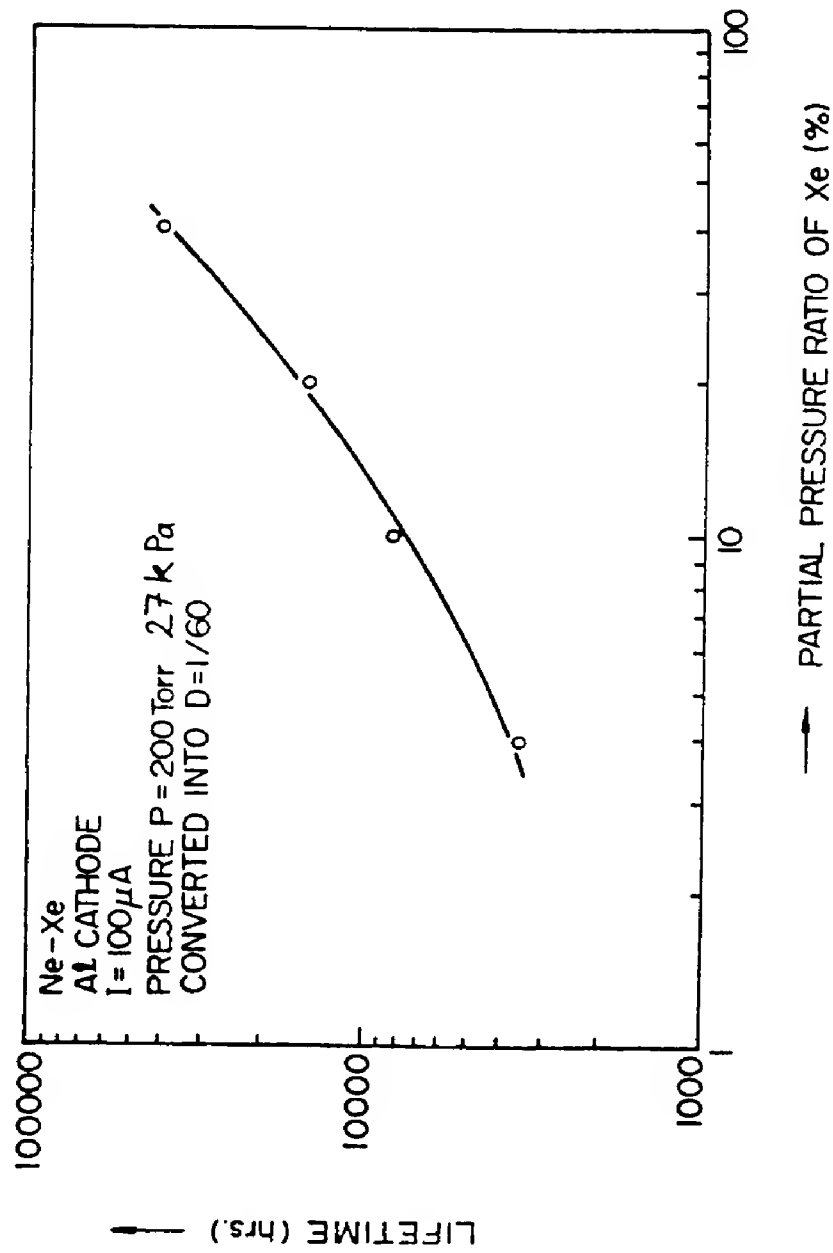


FIG. 17

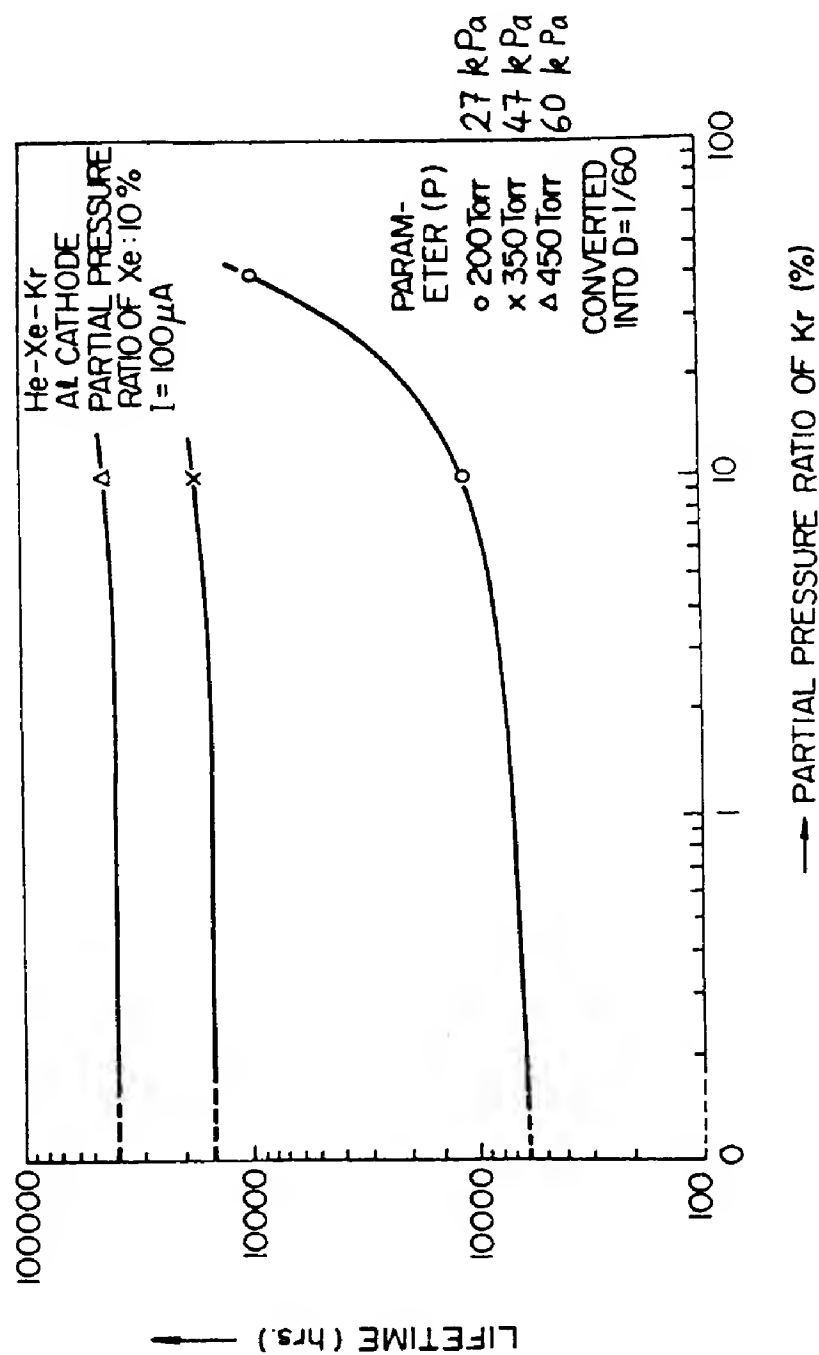


FIG. 18

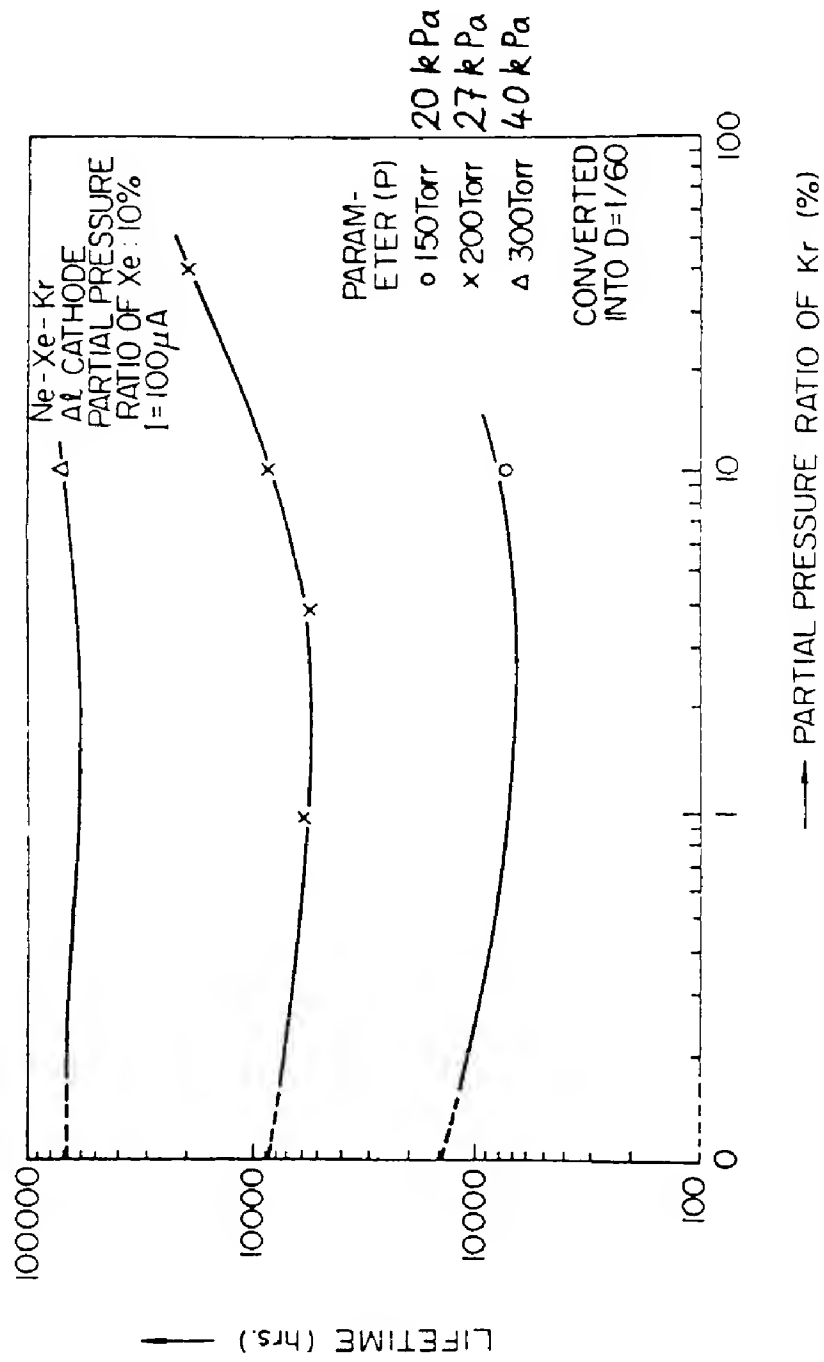


FIG. 19

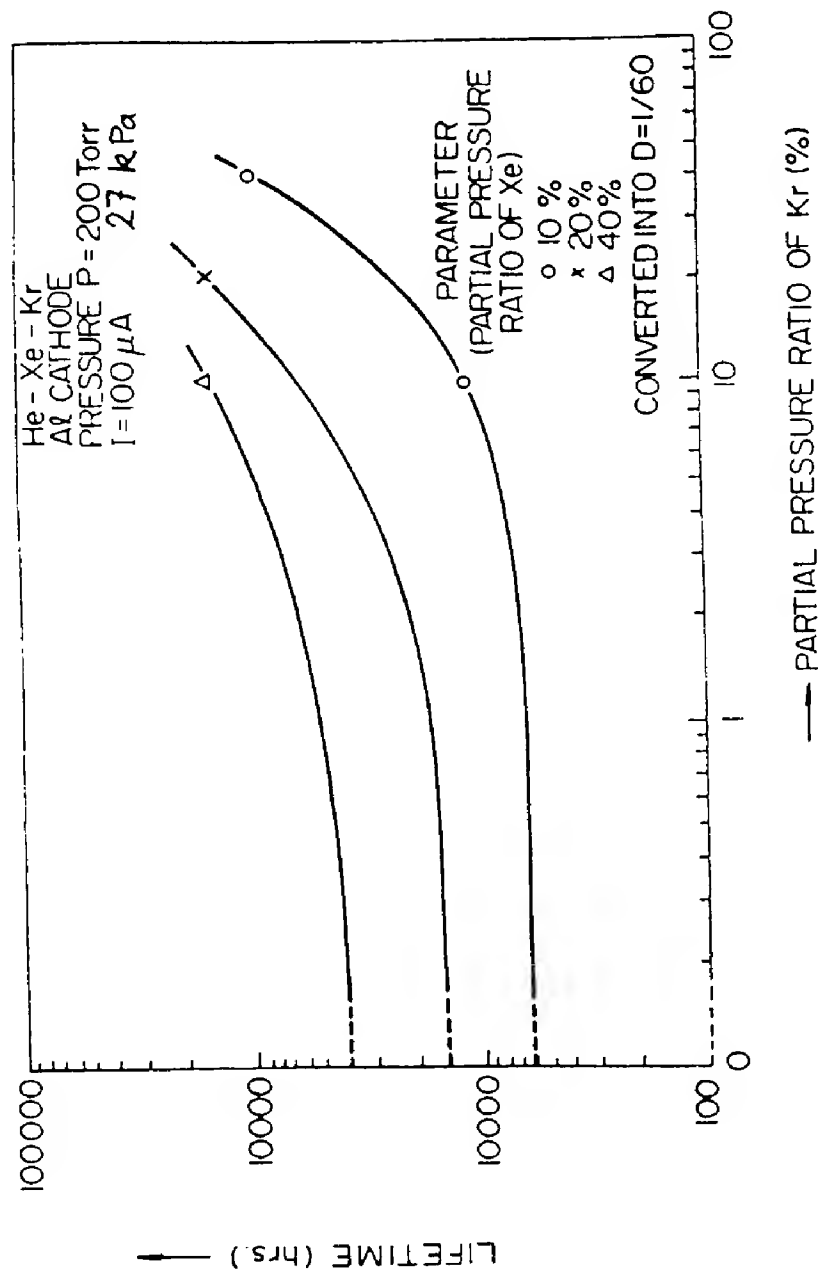


FIG. 20

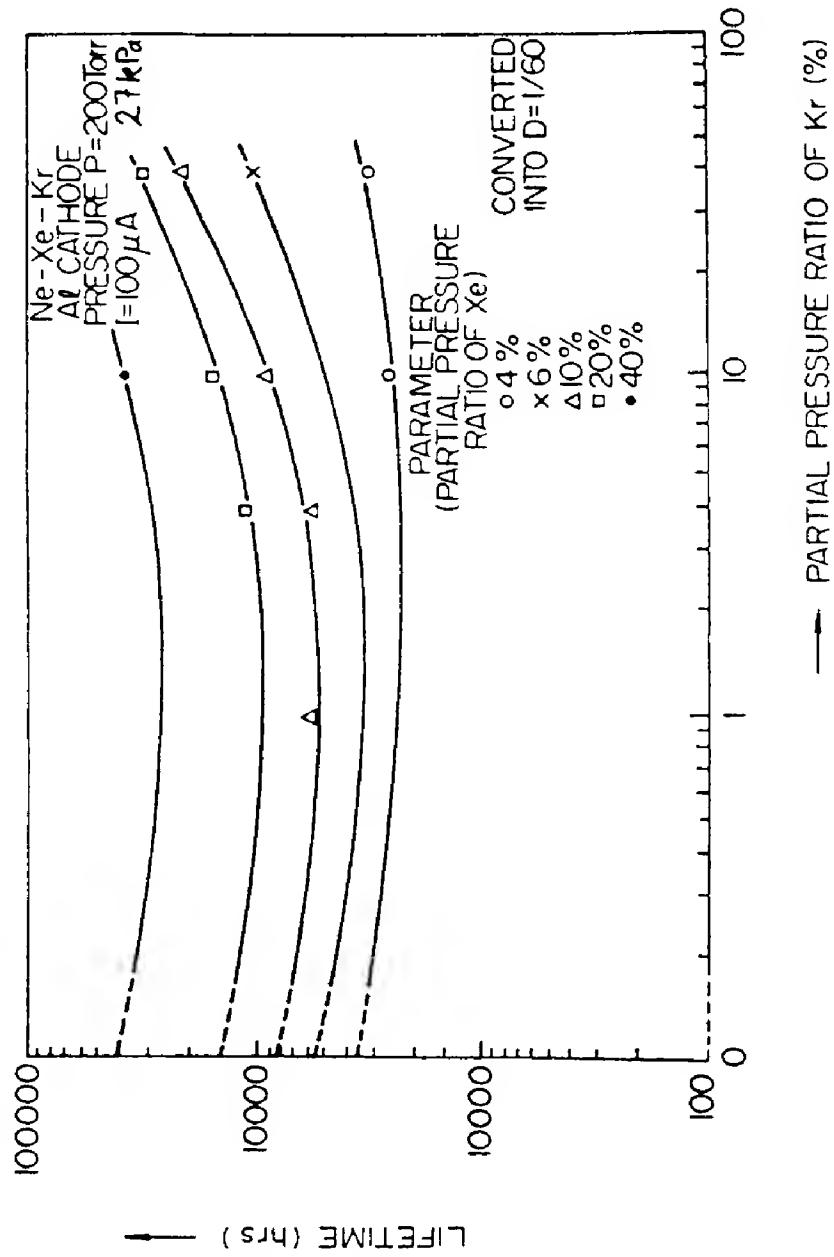


FIG. 21

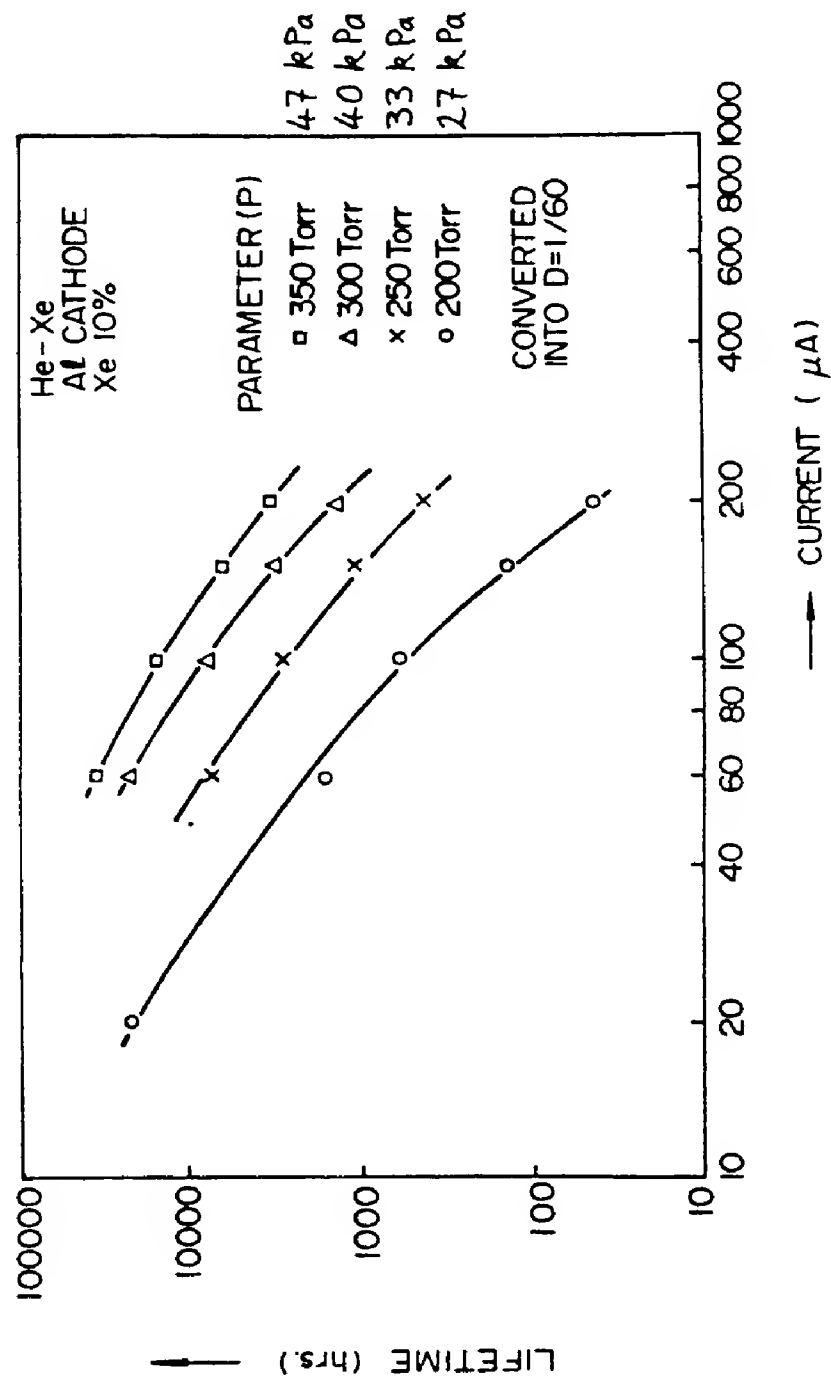


FIG. 22

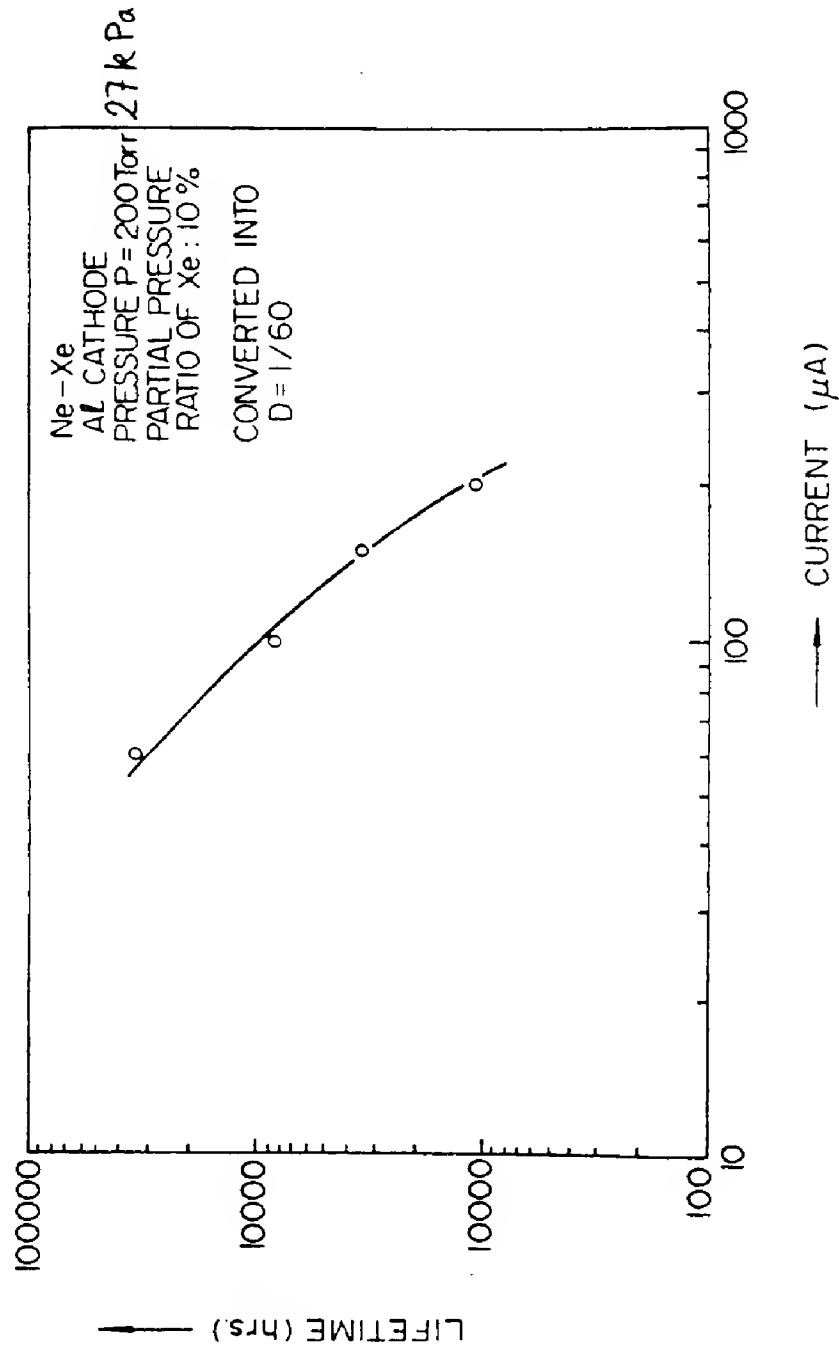


FIG. 23

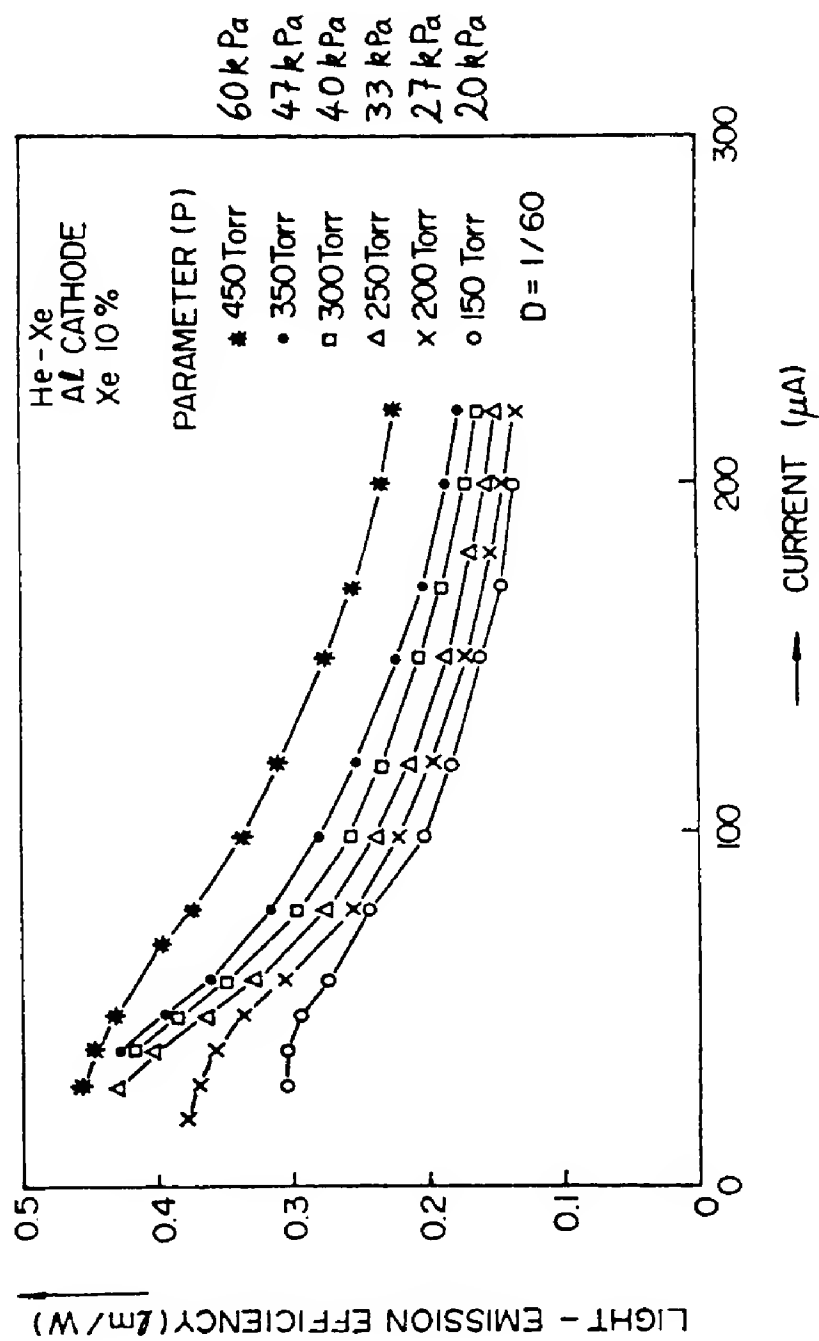


FIG. 24

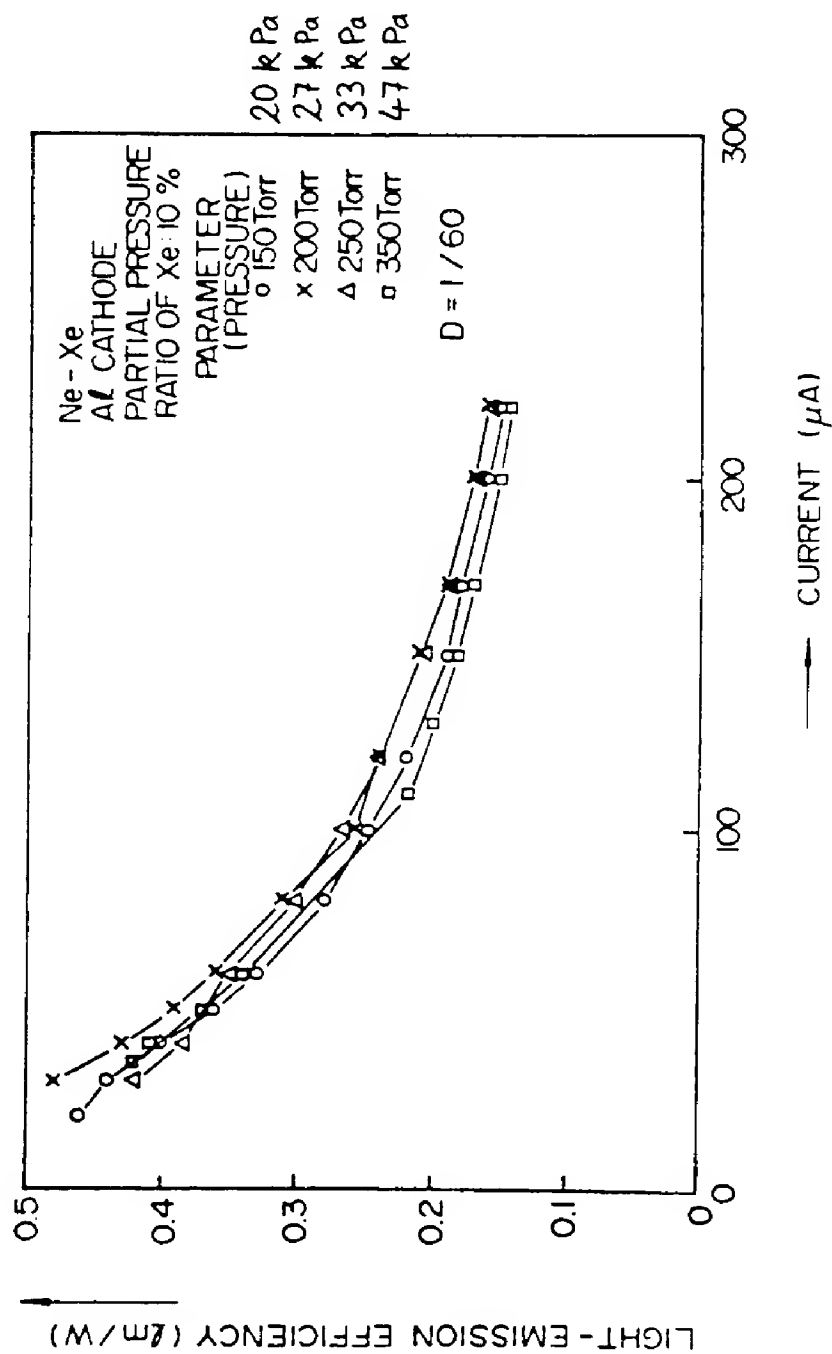


FIG. 25

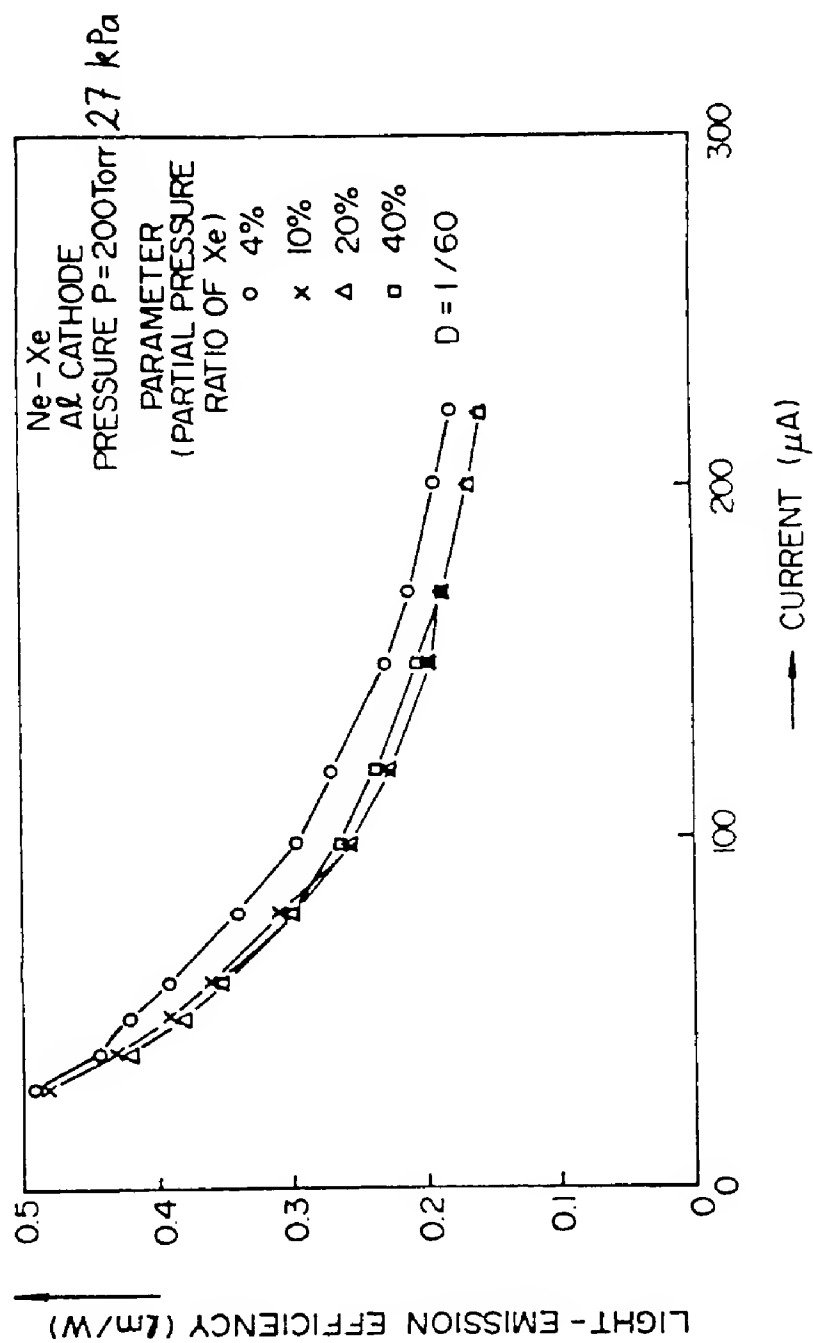


FIG. 26

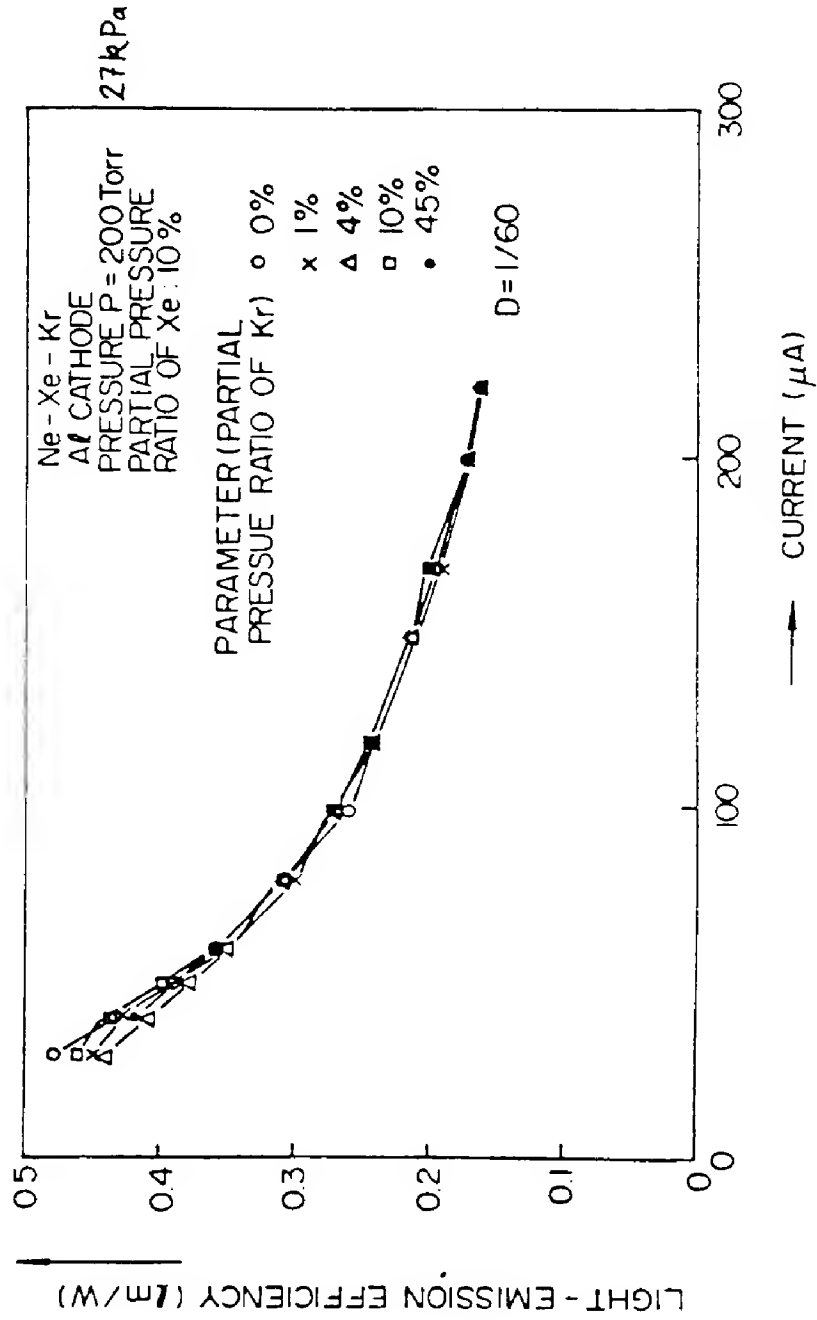


FIG. 27

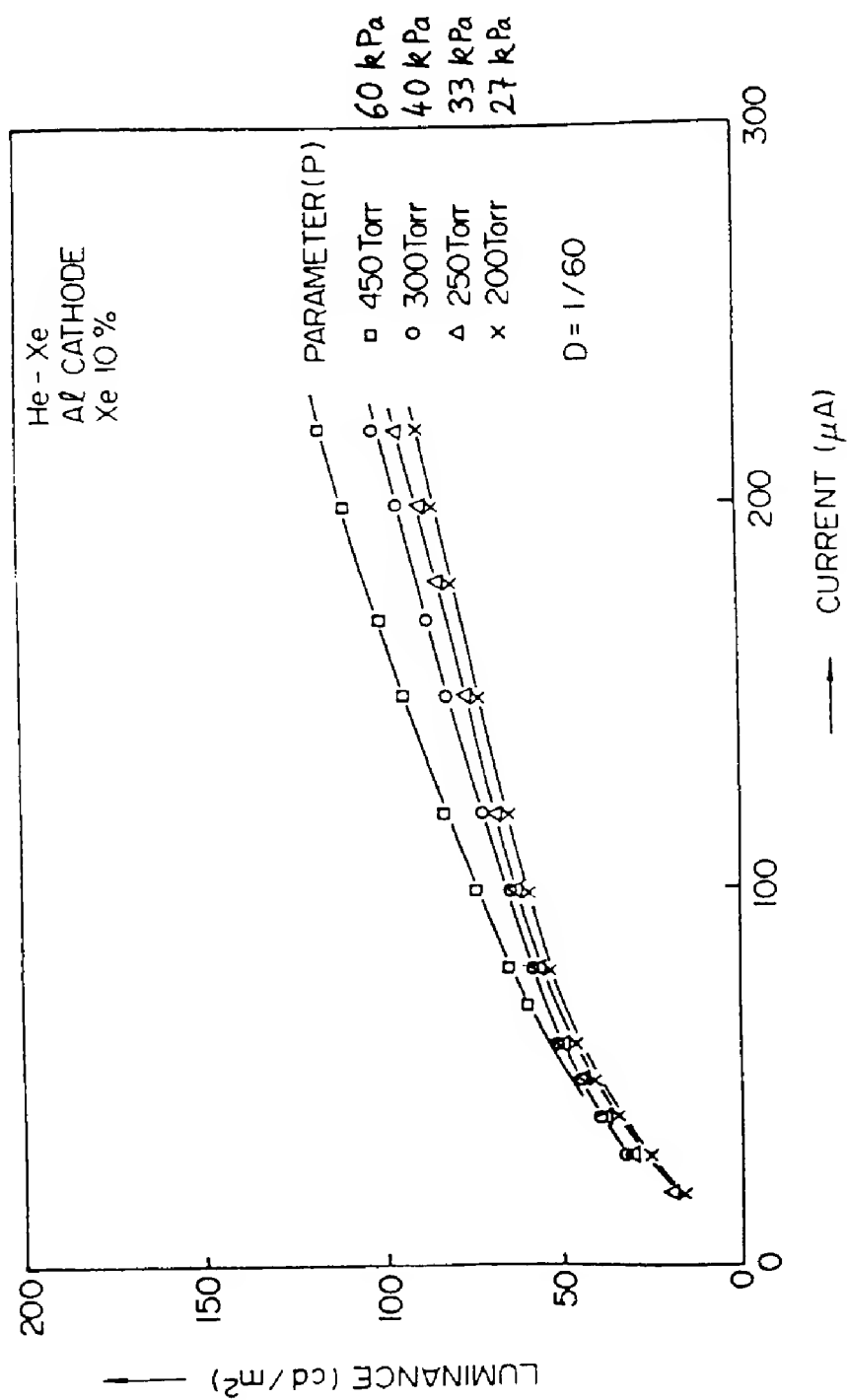


FIG. 28

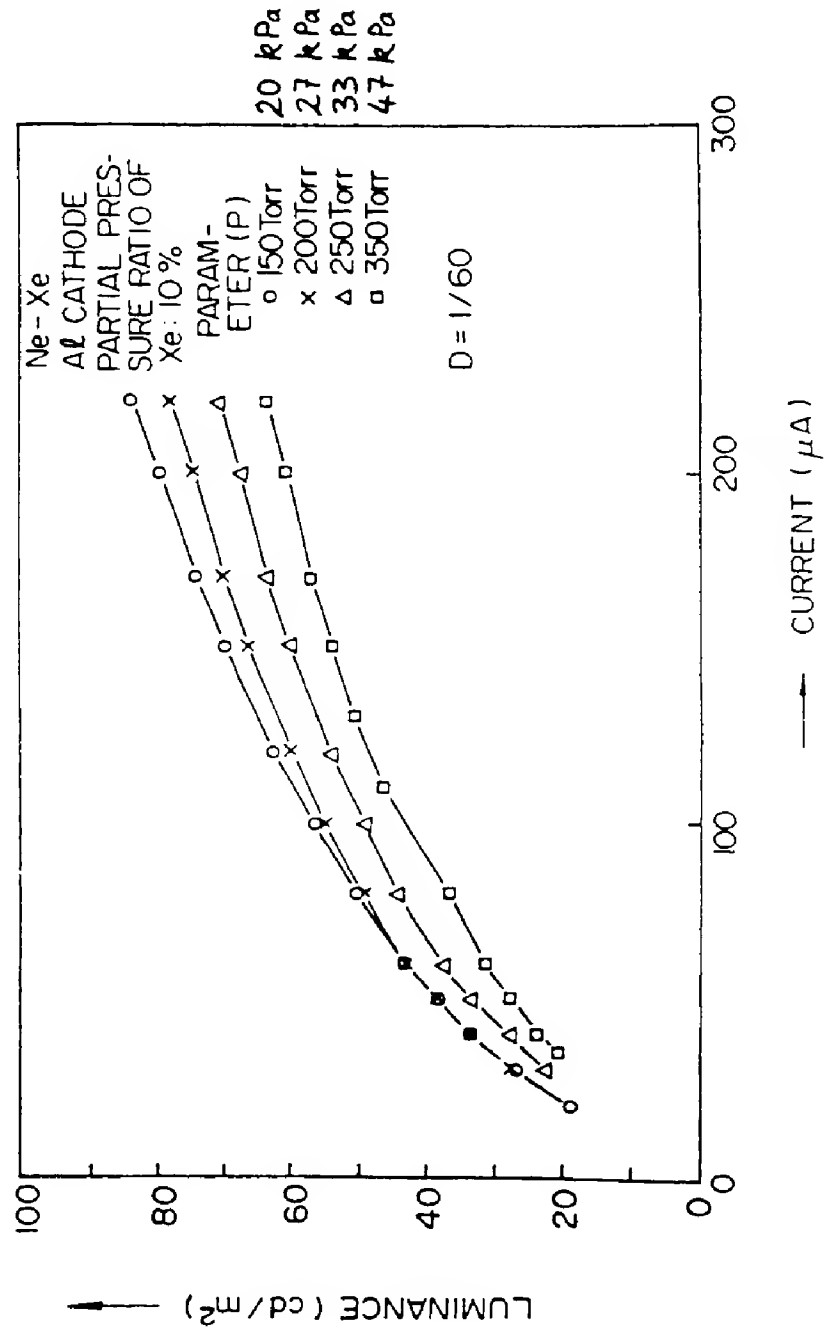


FIG. 29

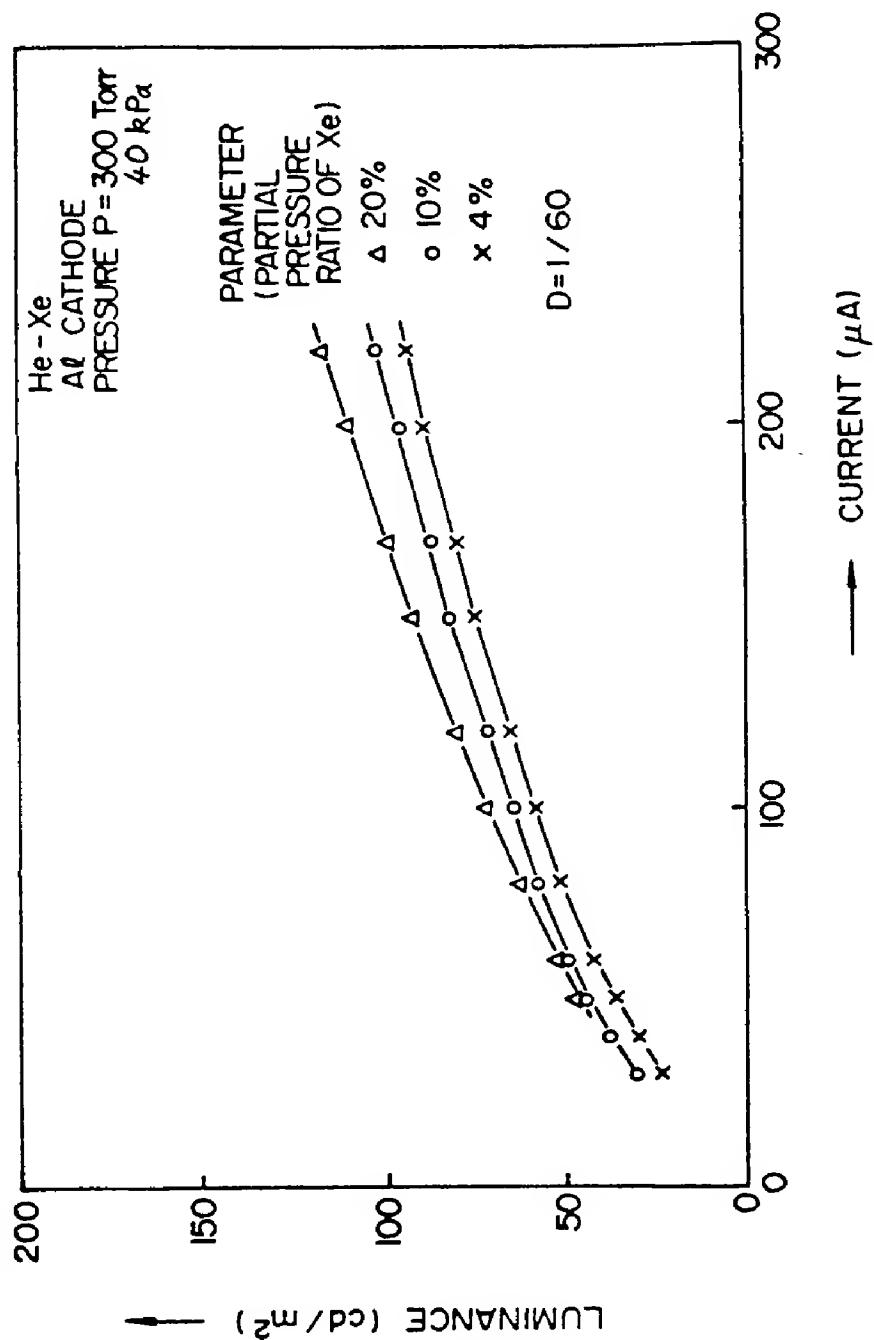


FIG. 30

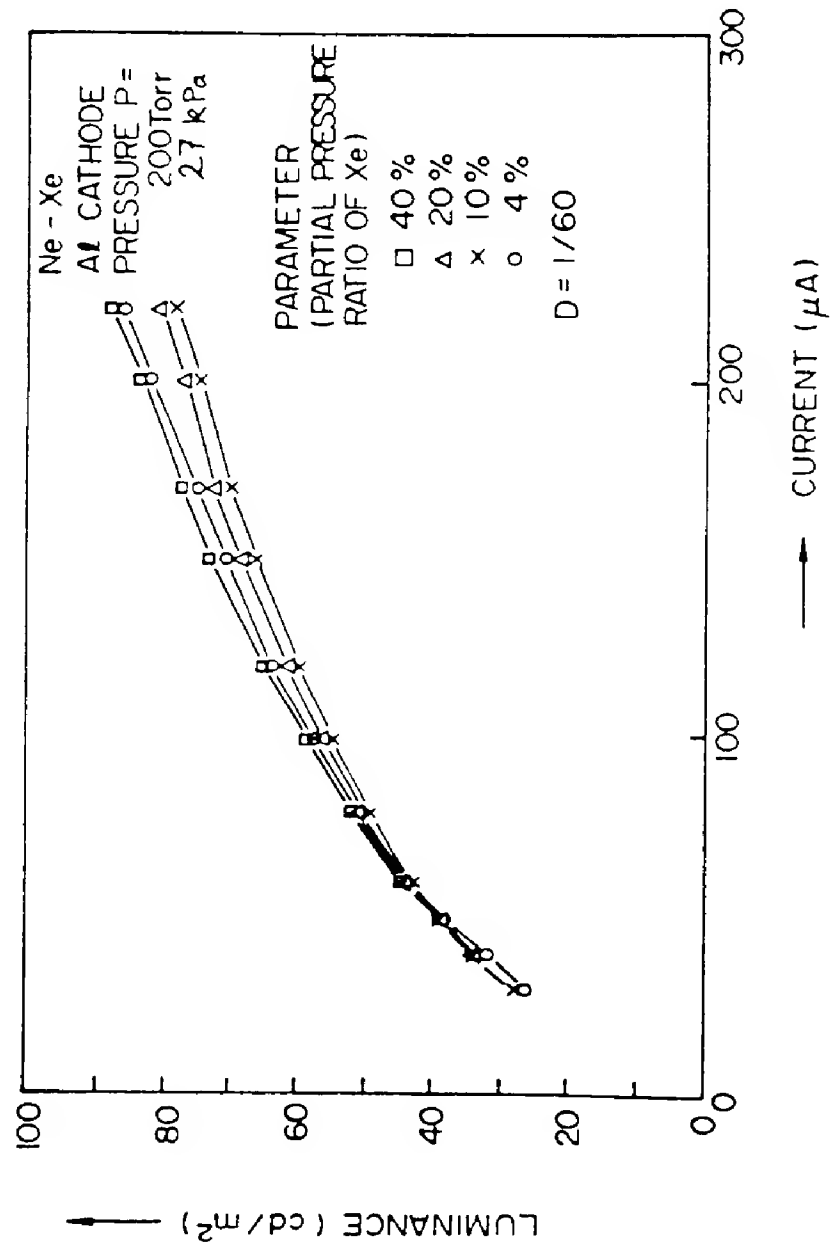


FIG. 31

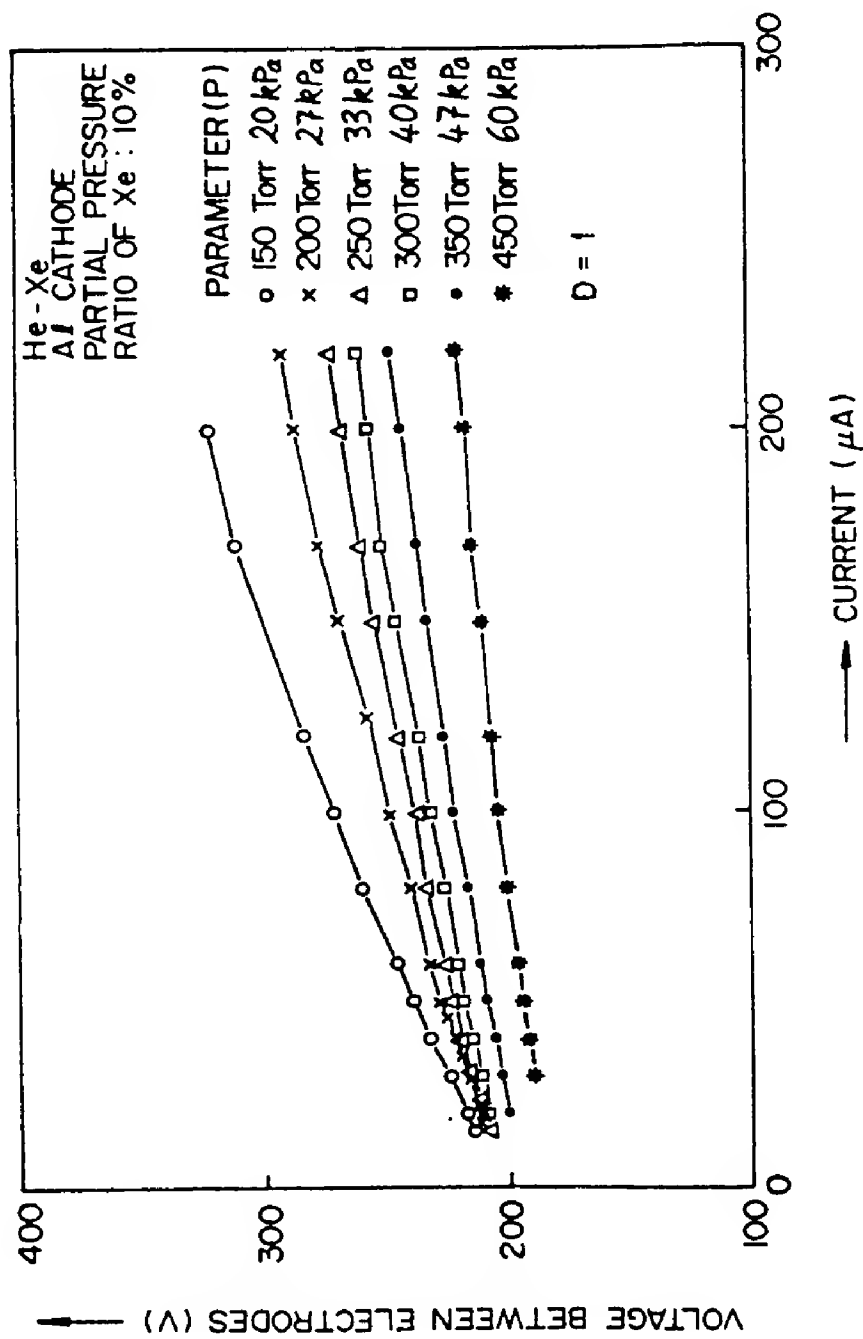


FIG. 32

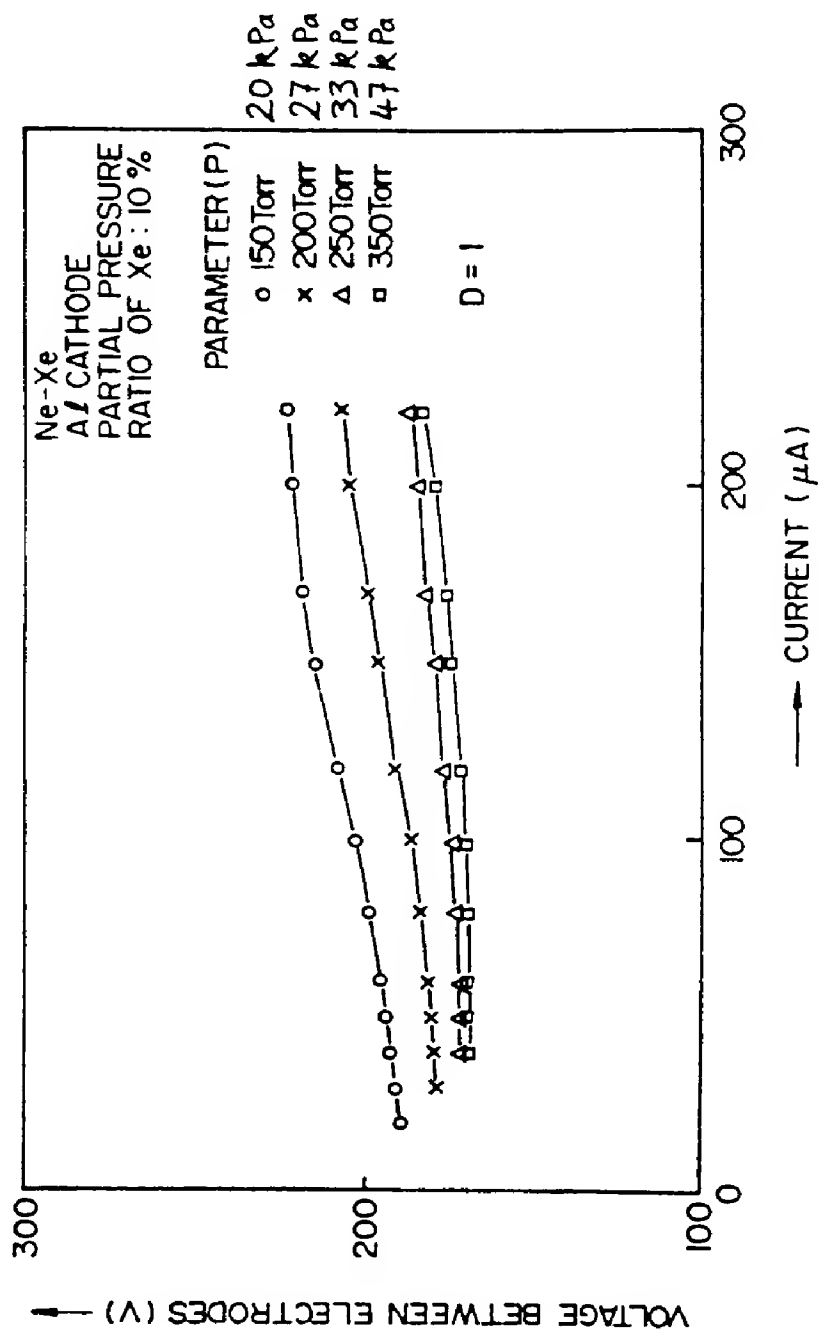


FIG. 33

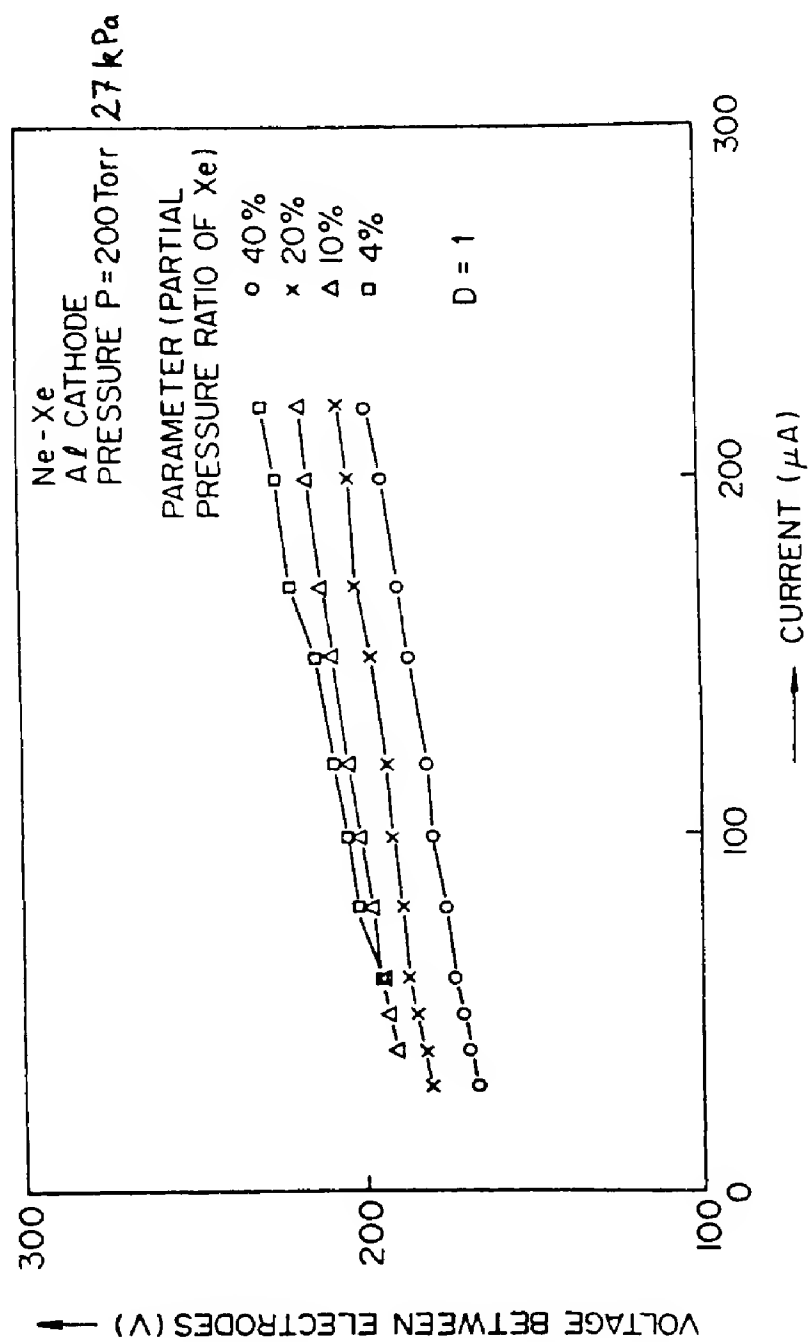


FIG. 34

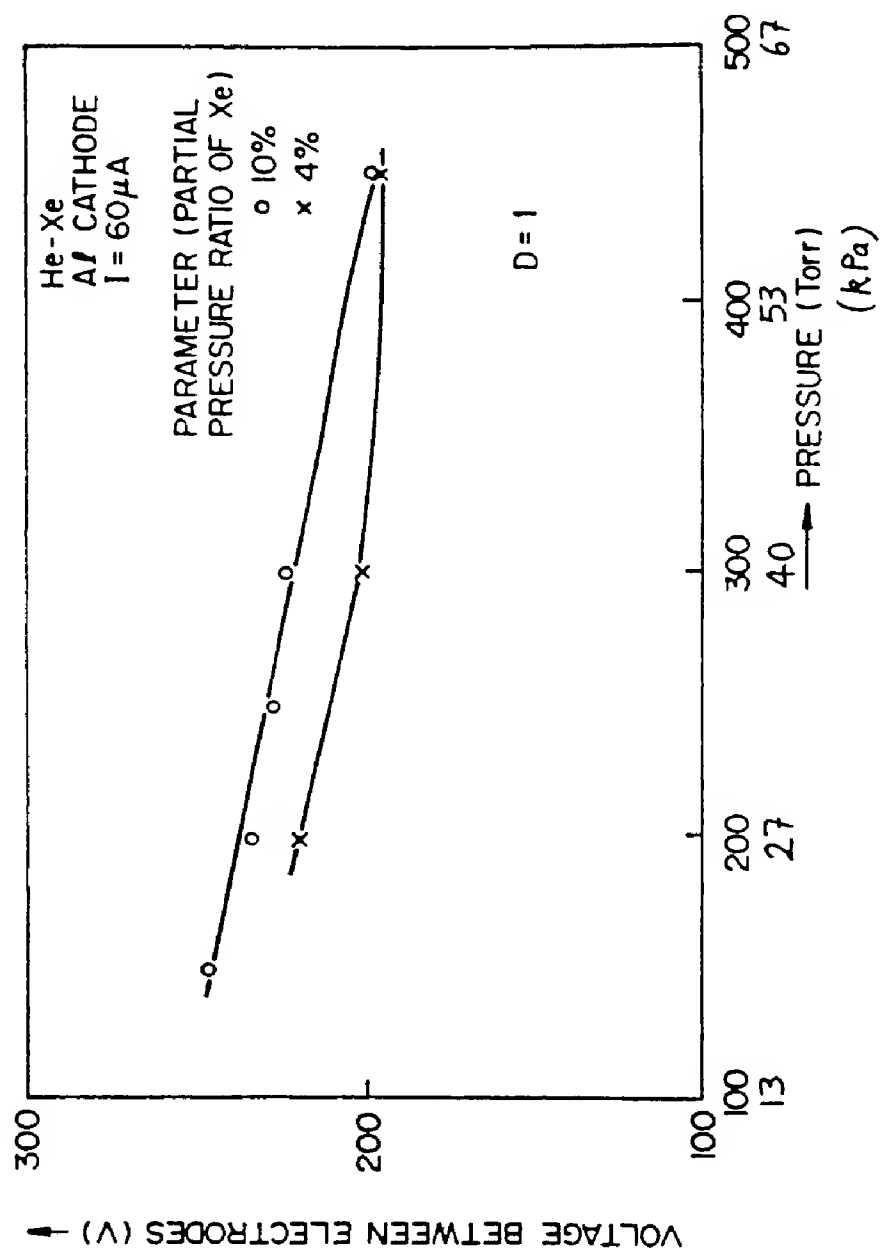


FIG. 35

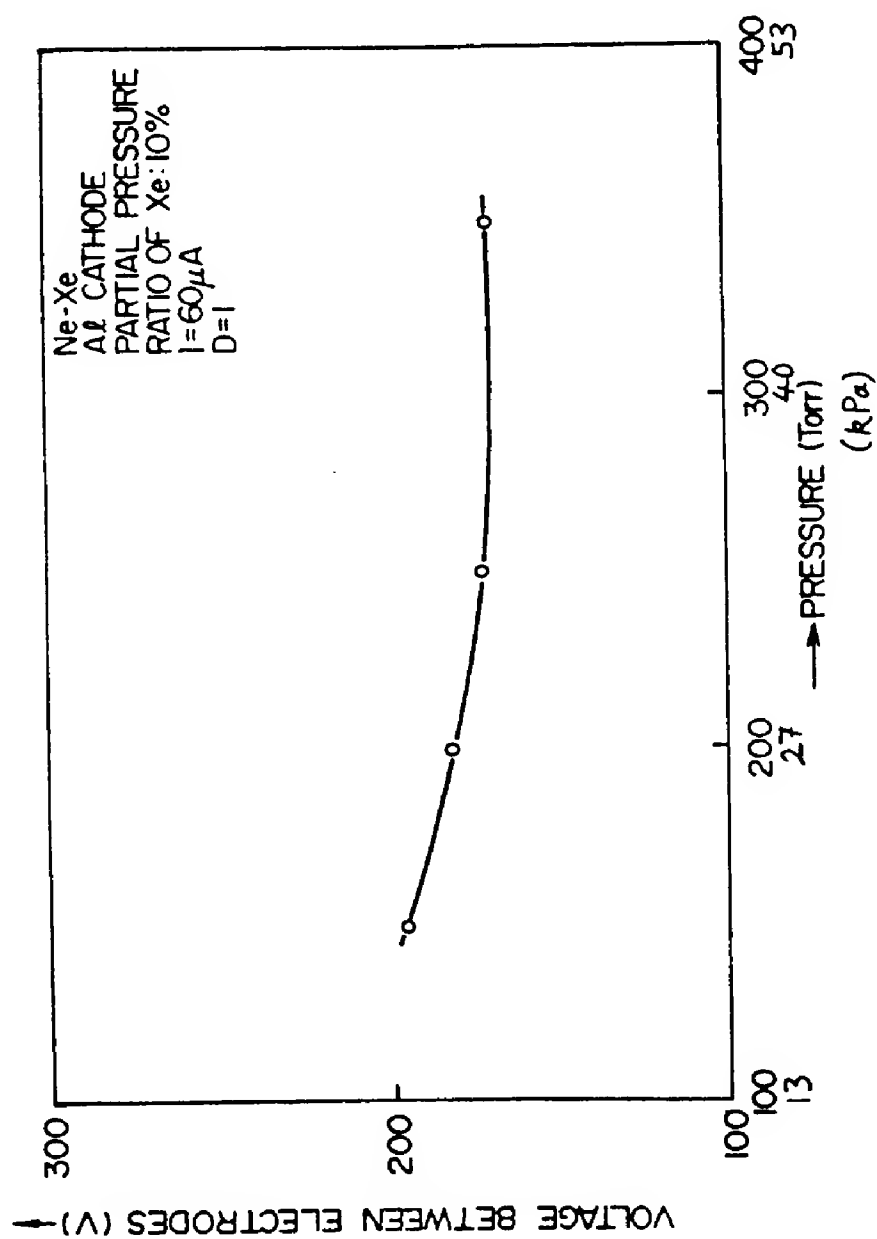


FIG. 36

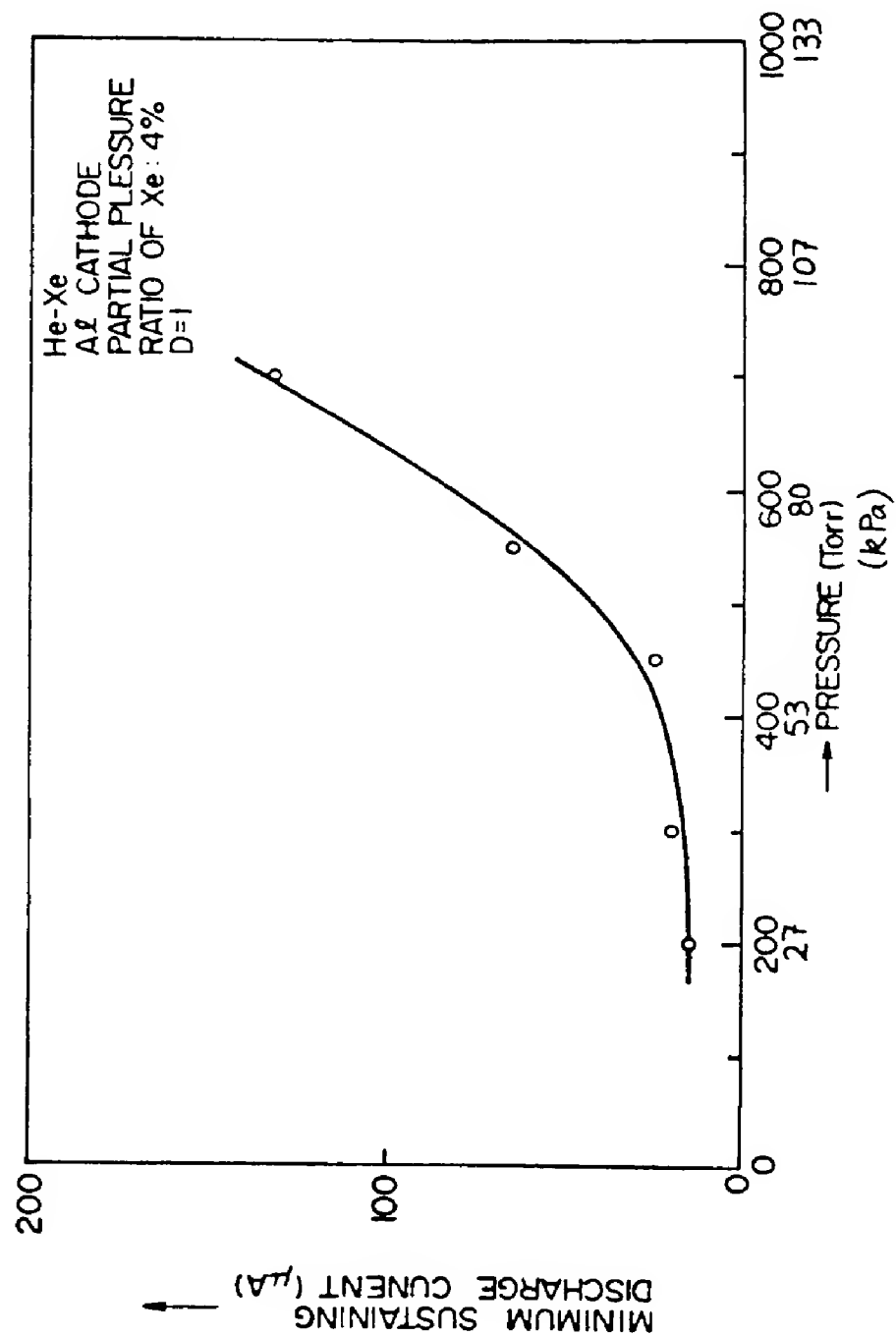


FIG. 37

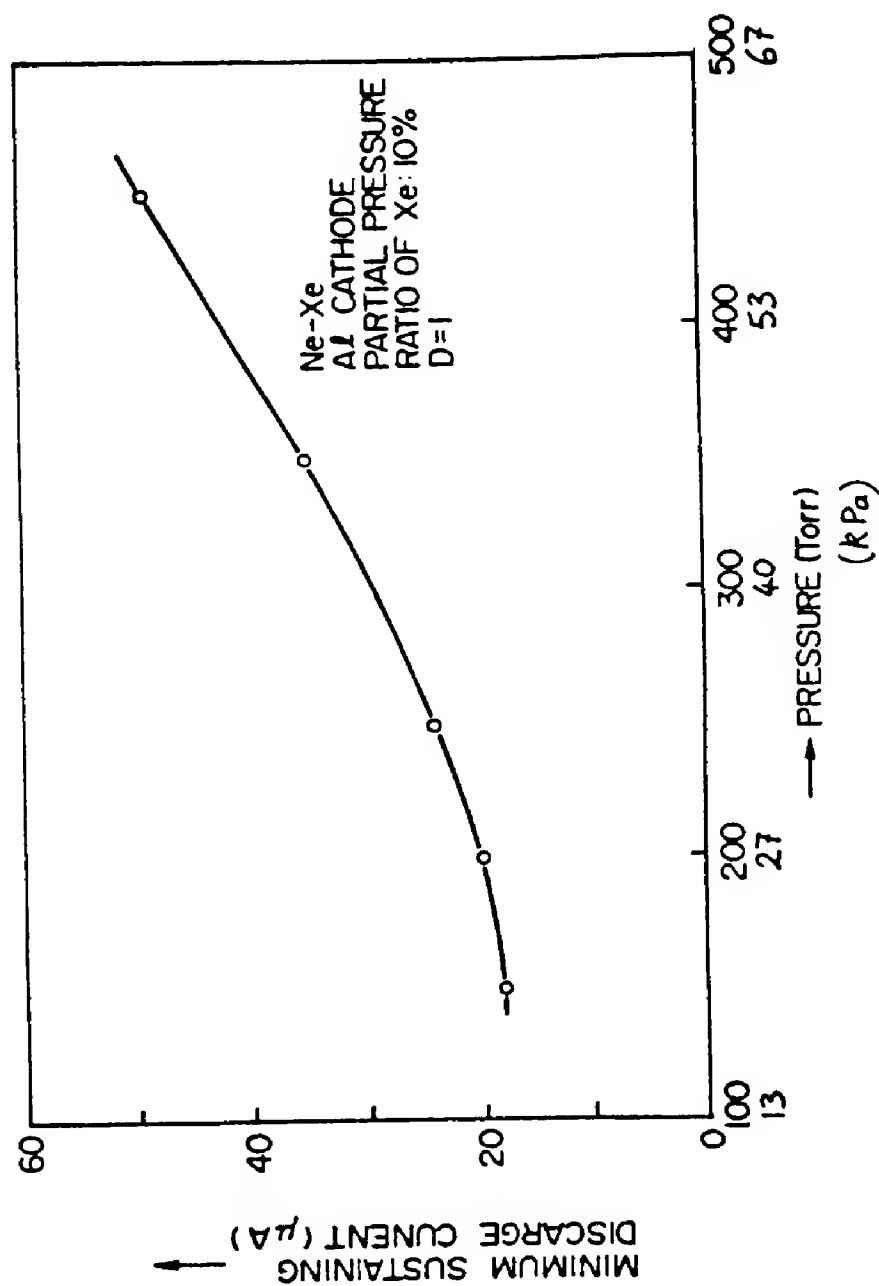


FIG. 38

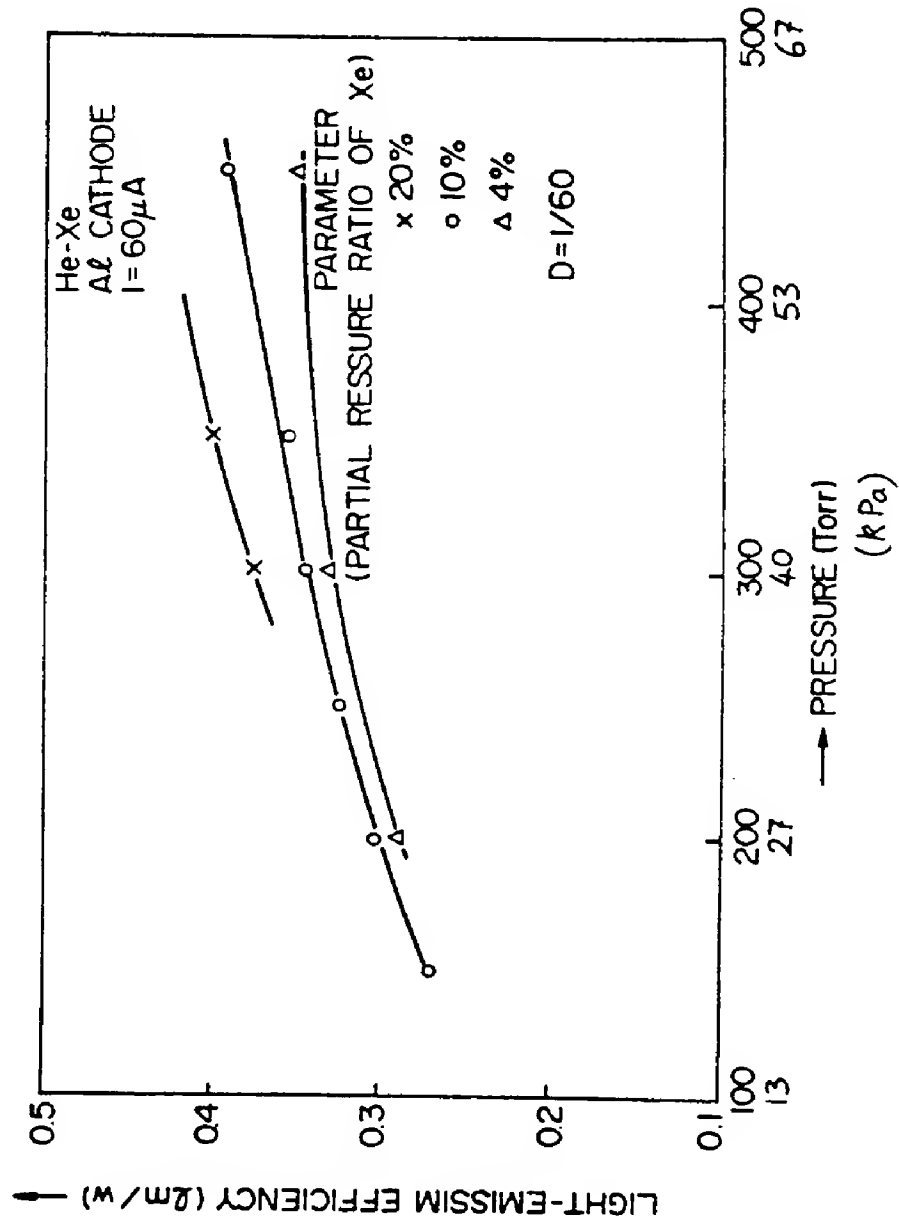


FIG. 39

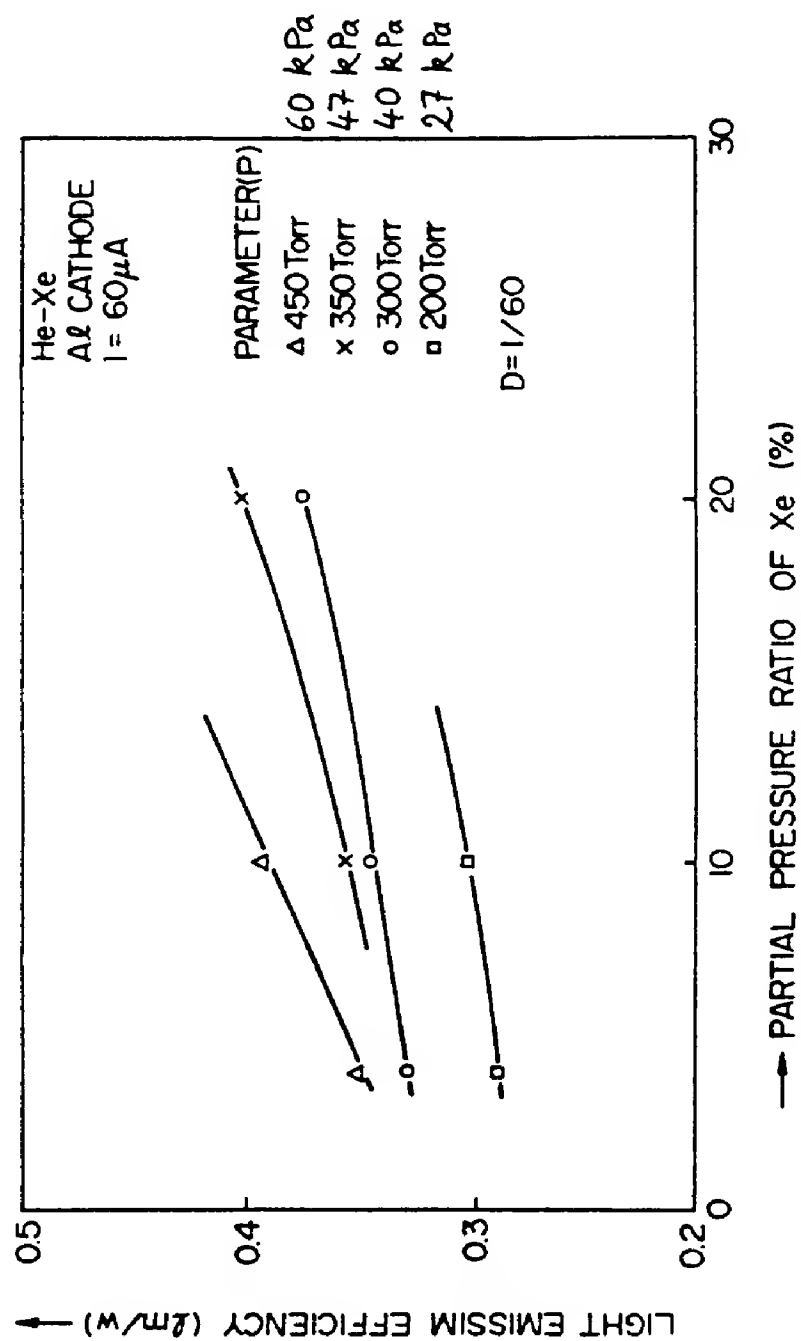


FIG. 40

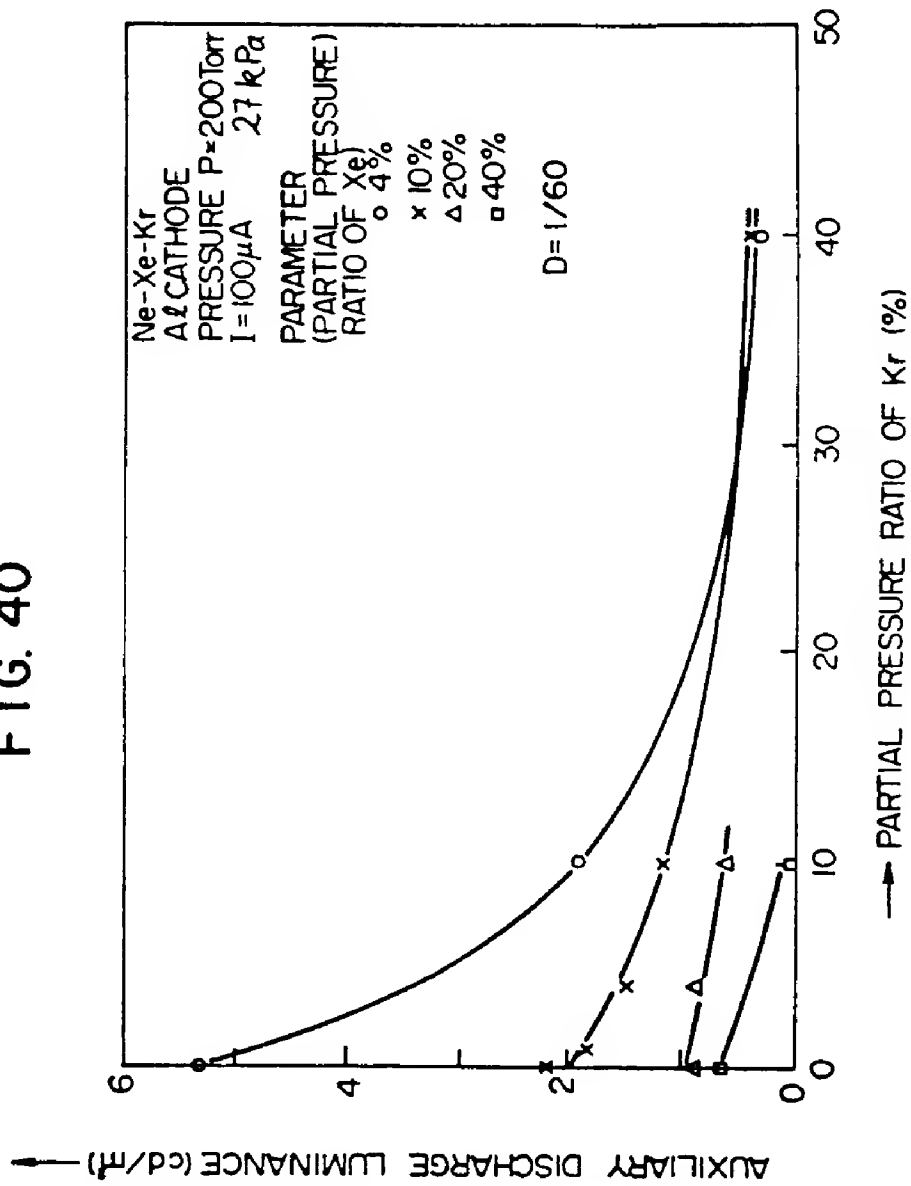


FIG. 41

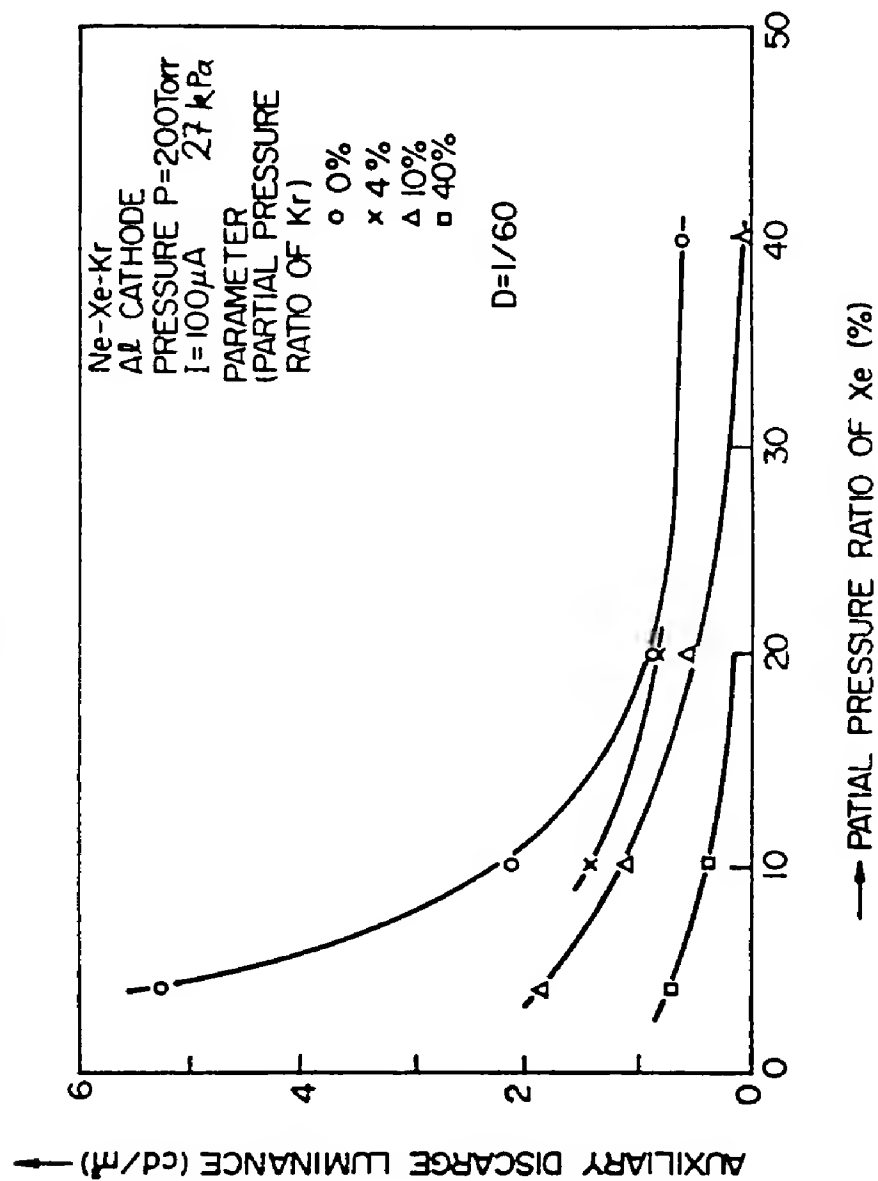


FIG. 42

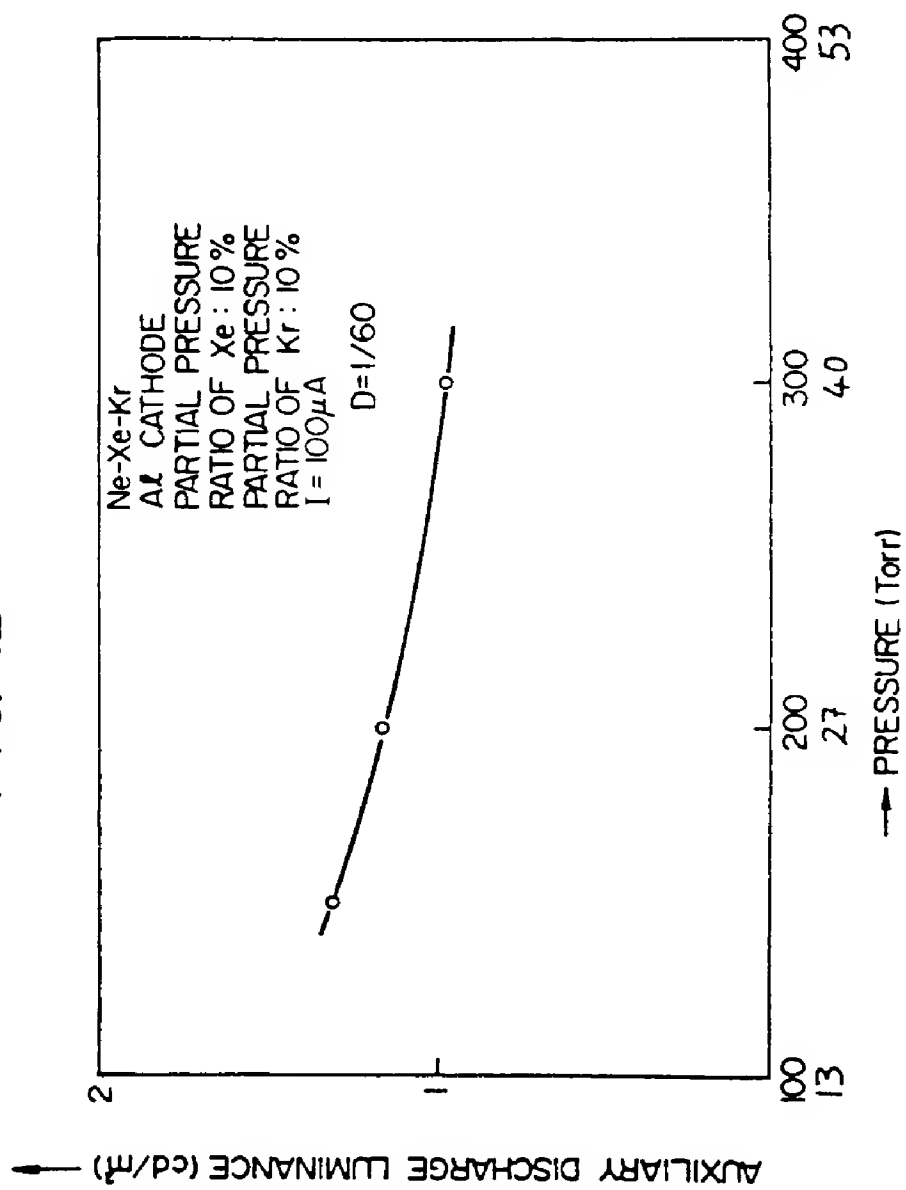


FIG. 43

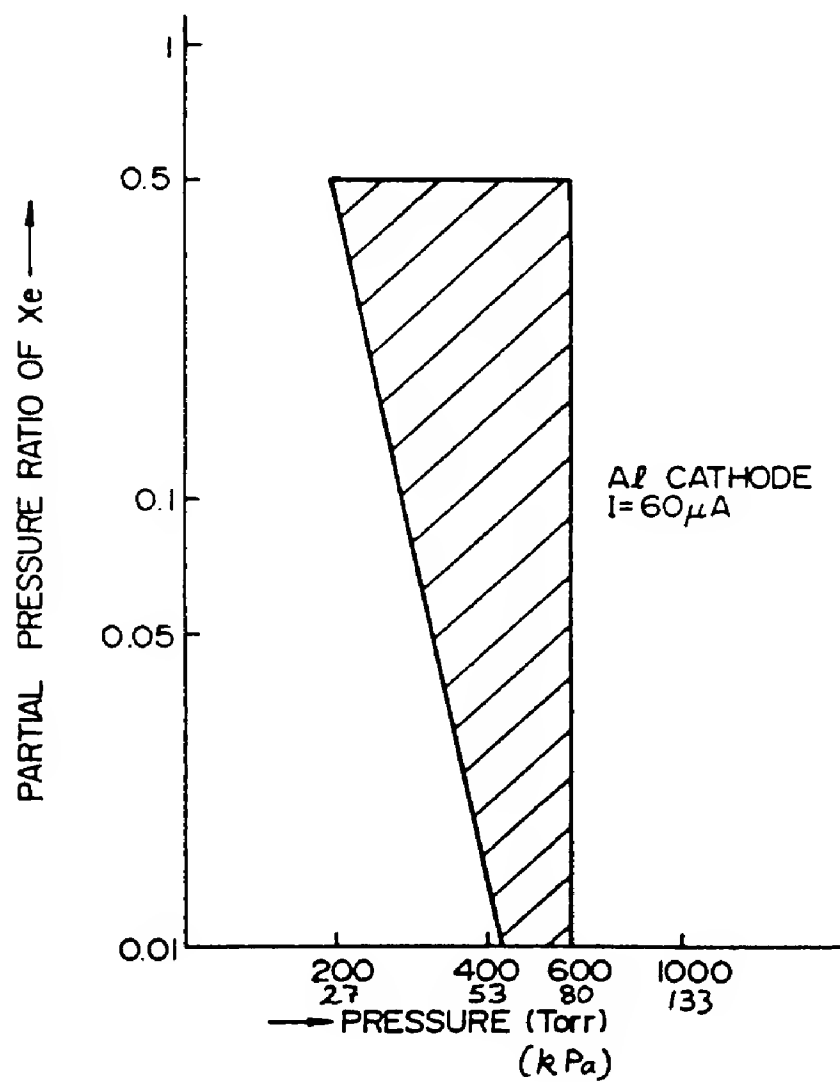


FIG. 44

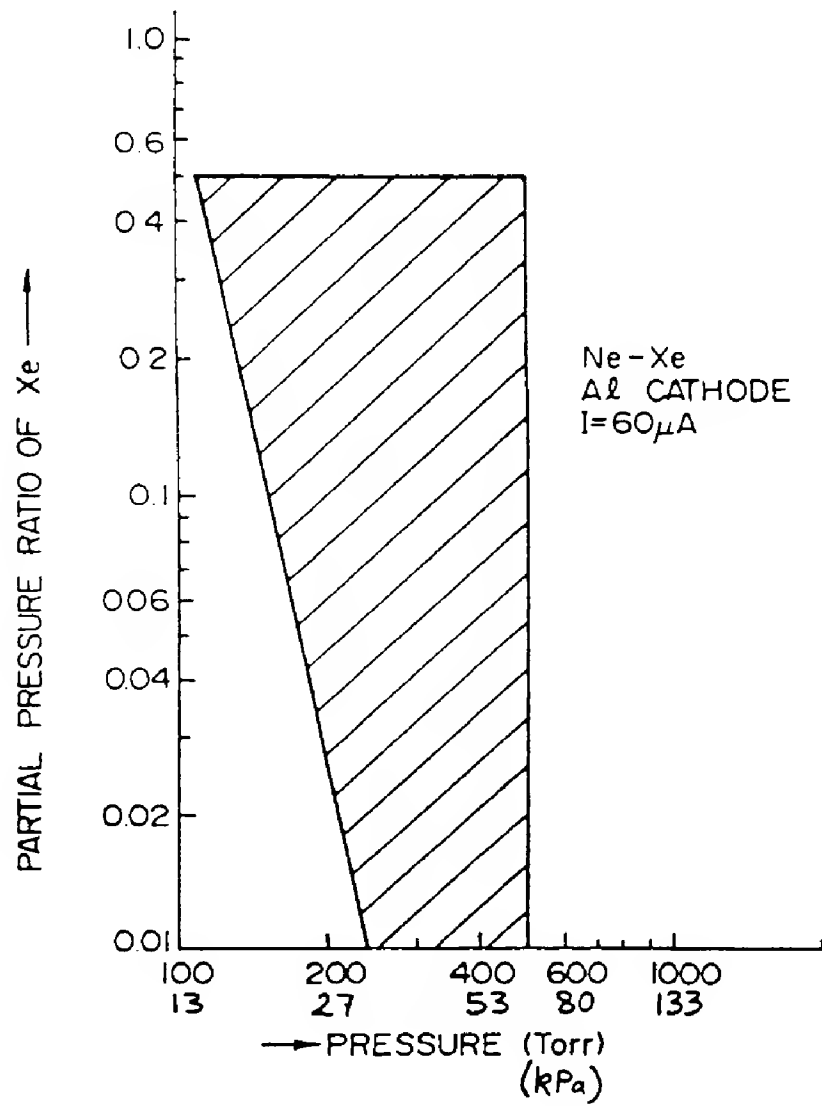


FIG. 45

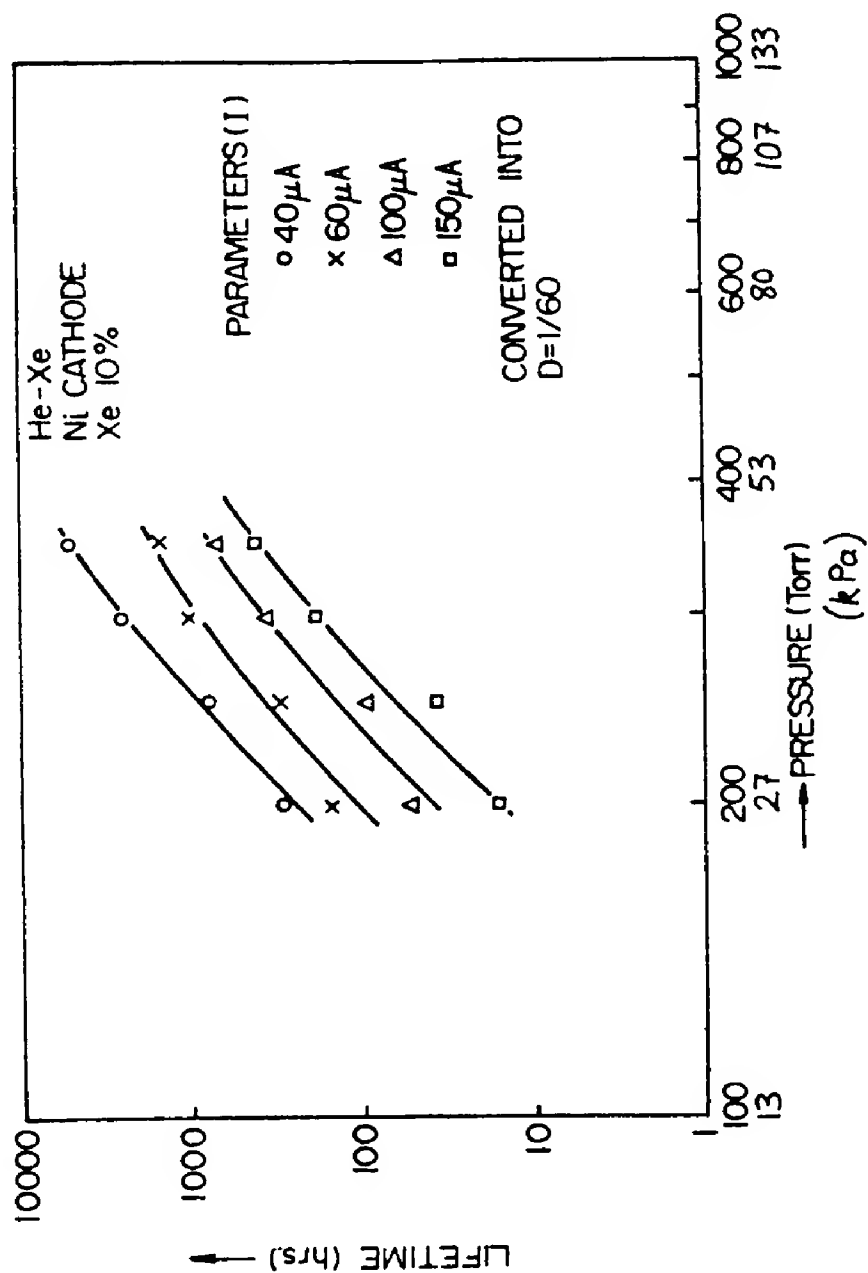


FIG. 46A

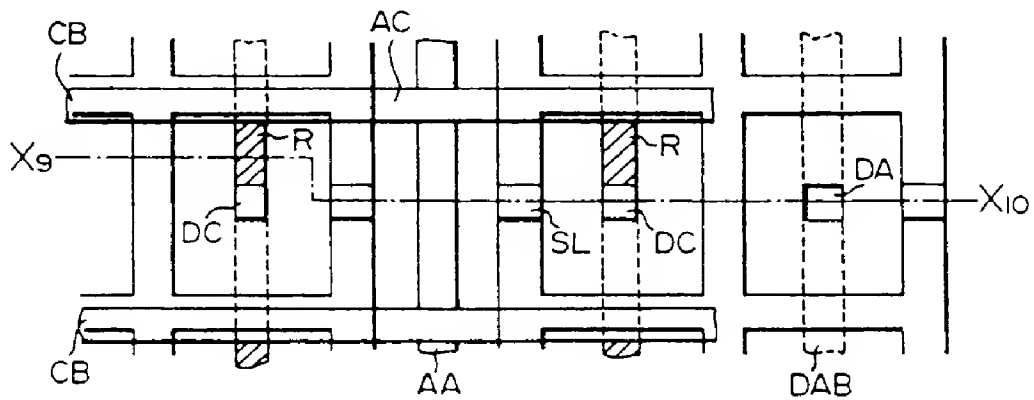


FIG. 46B

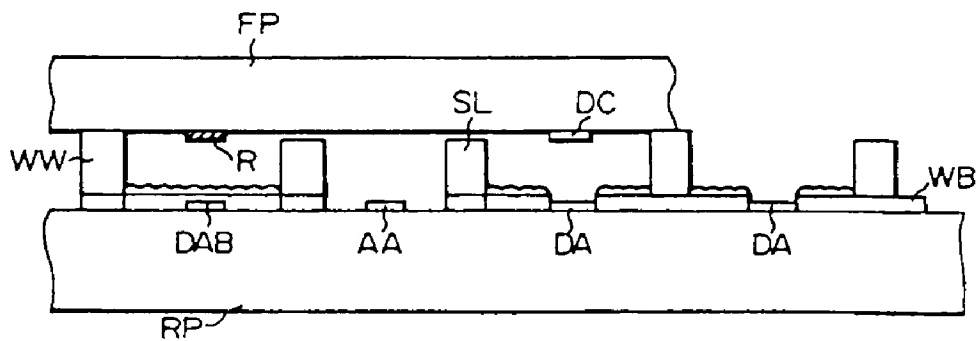


FIG. 47A

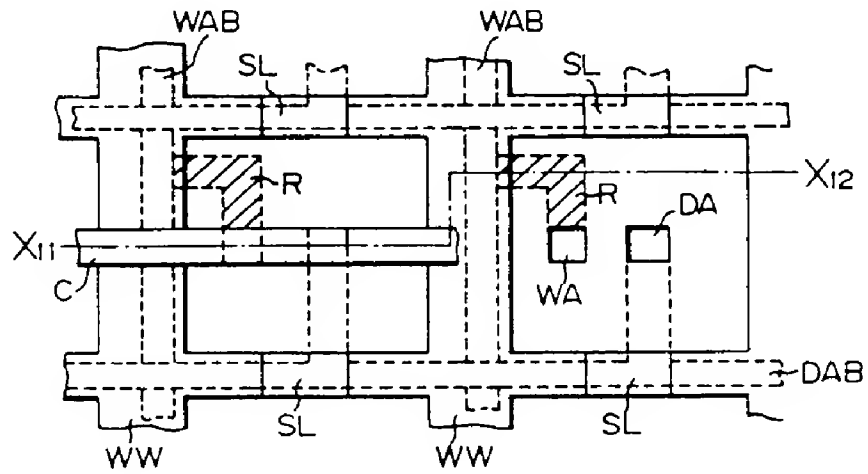


FIG. 47B

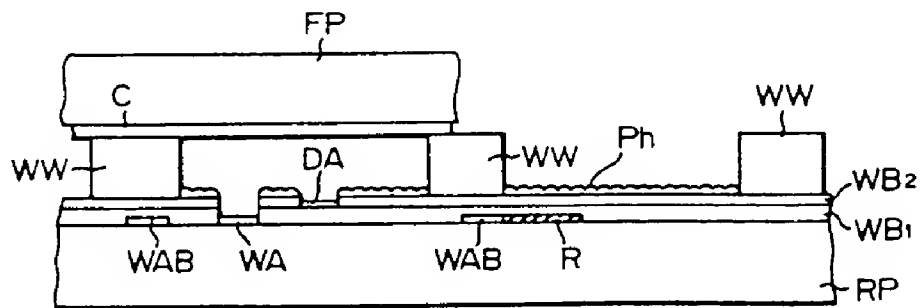


FIG. 48A

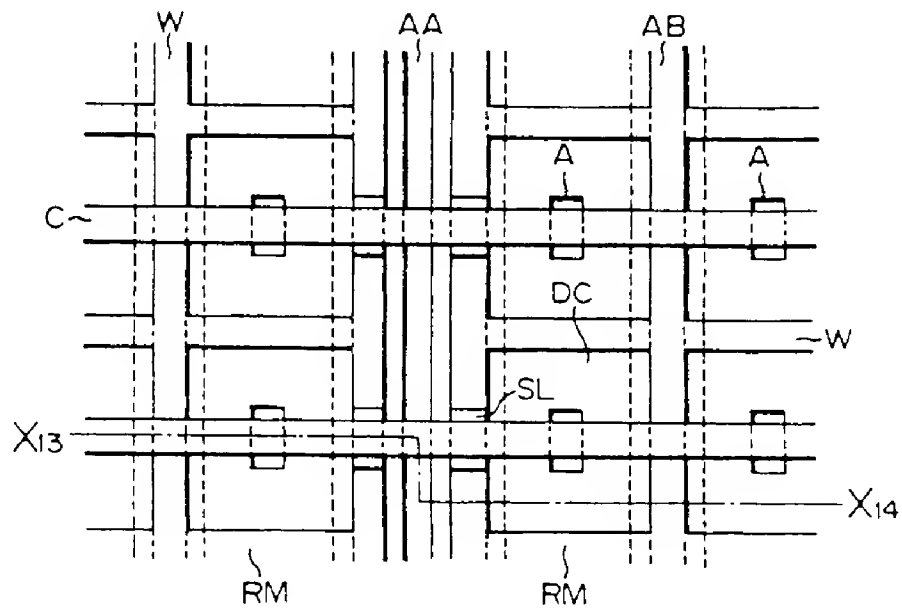


FIG. 48B

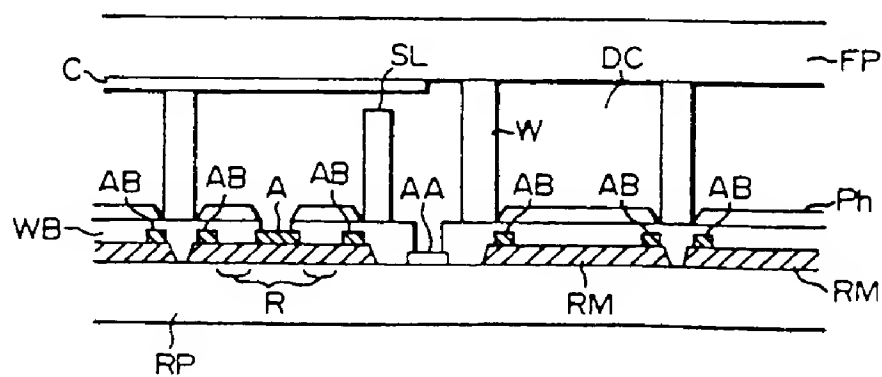


FIG. 49A

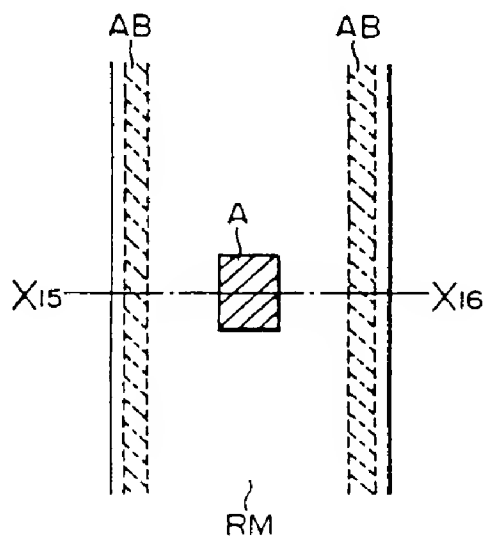


FIG. 49B

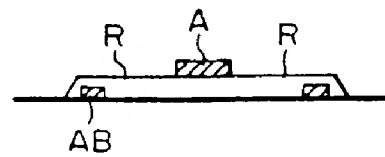


FIG. 50A

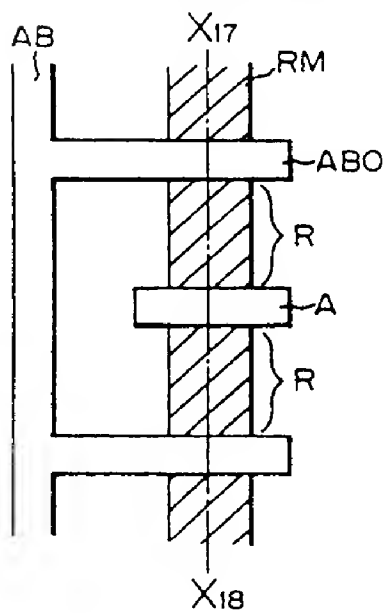


FIG. 50B

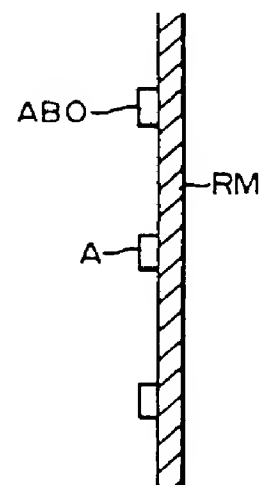


FIG. 5IA

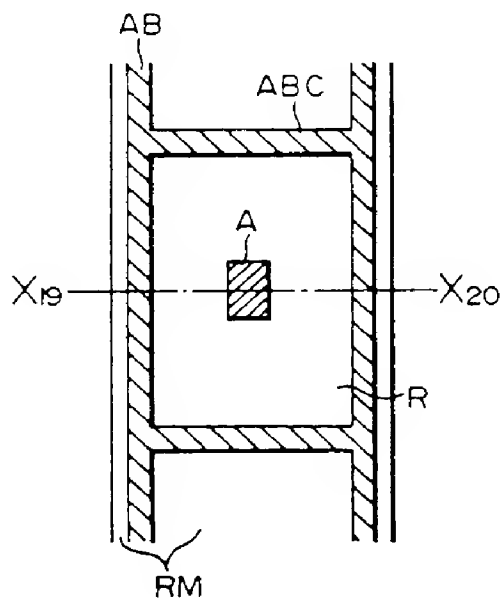


FIG. 5IB

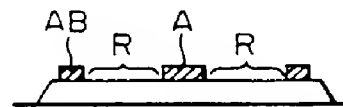


FIG. 52A

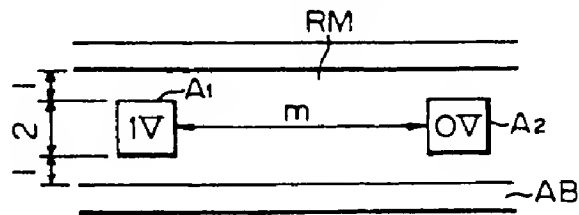


FIG. 52B

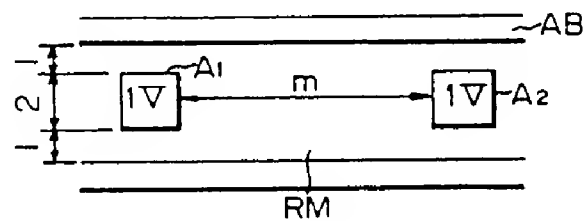


FIG. 52C

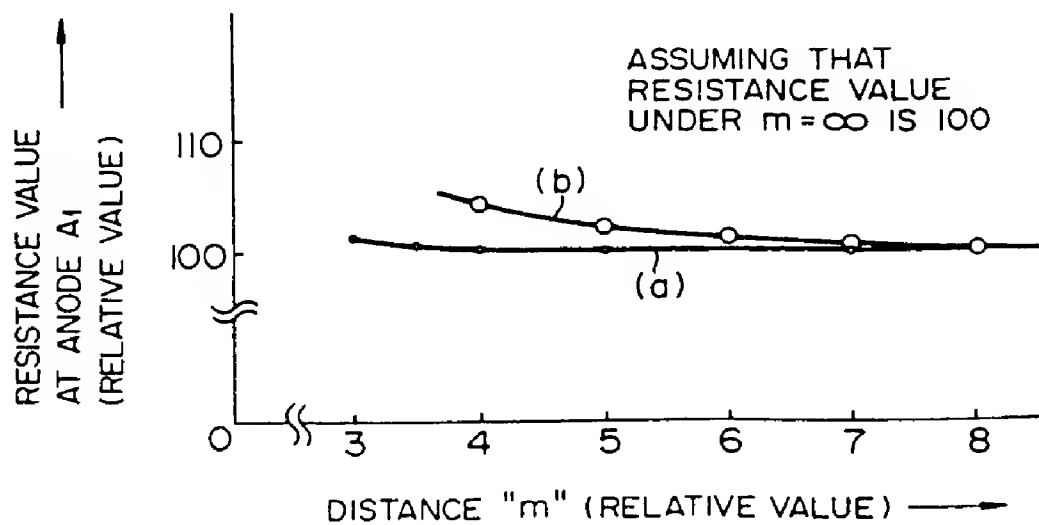


FIG. 53A

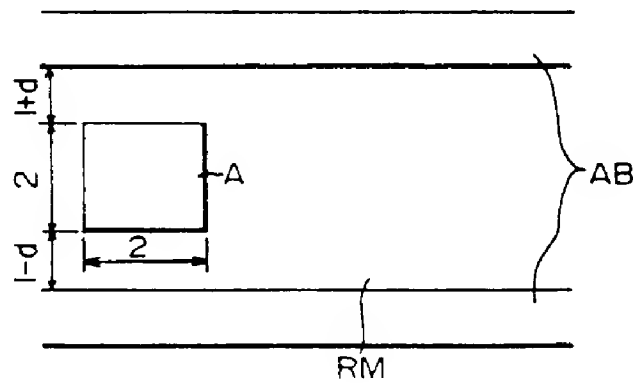


FIG. 53B

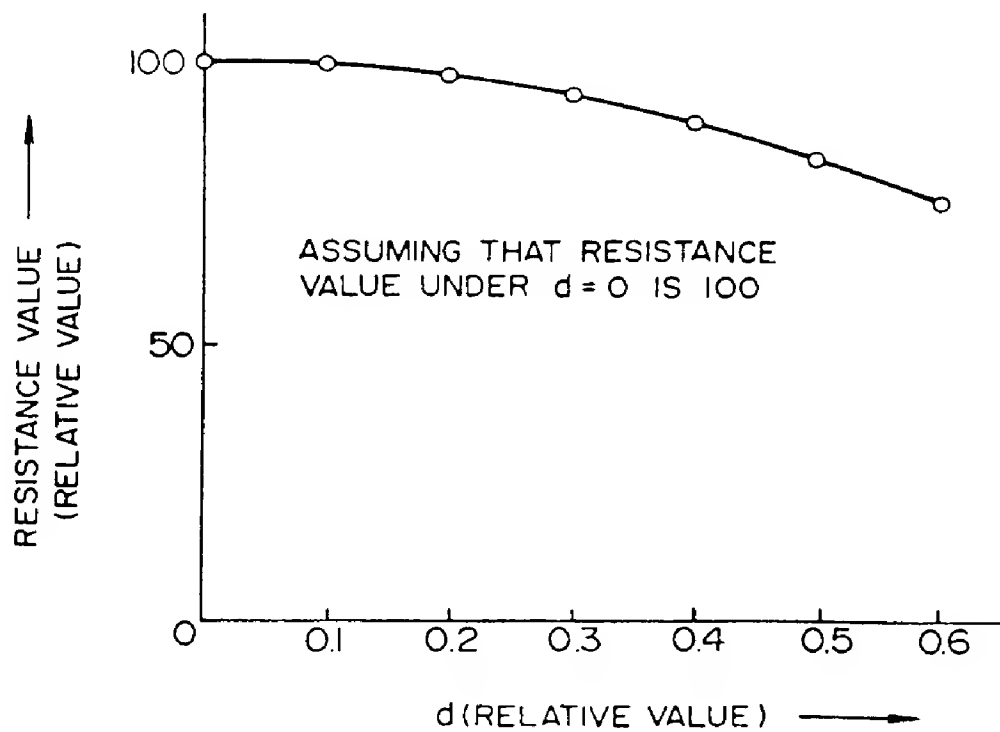


FIG. 54A

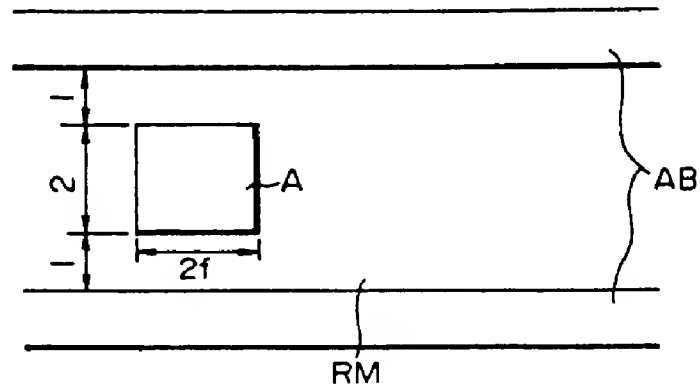


FIG. 54B

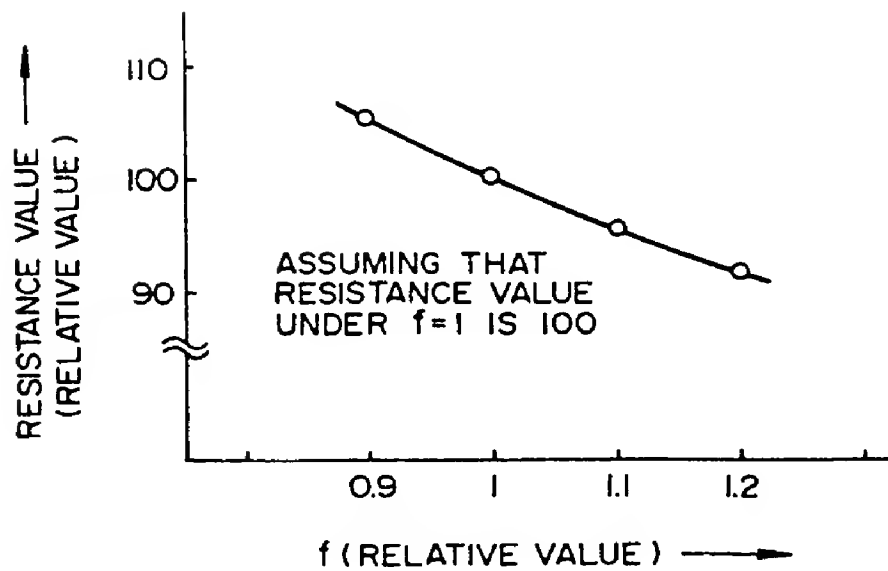


FIG. 55A

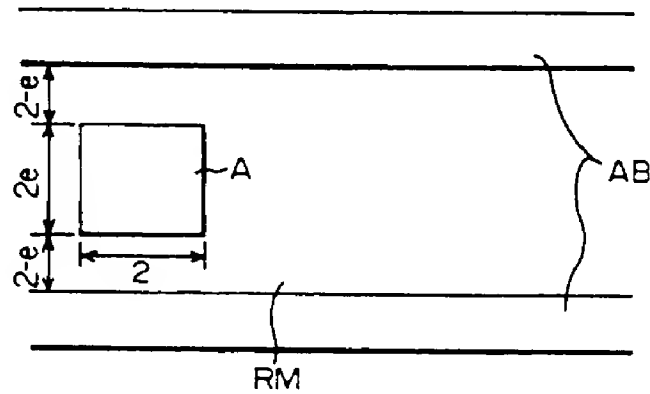


FIG. 55B

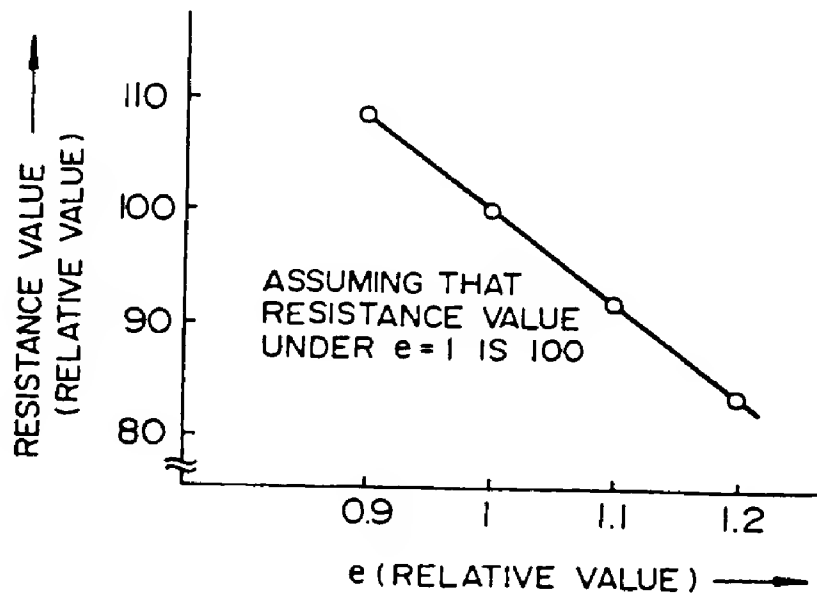


FIG. 56A

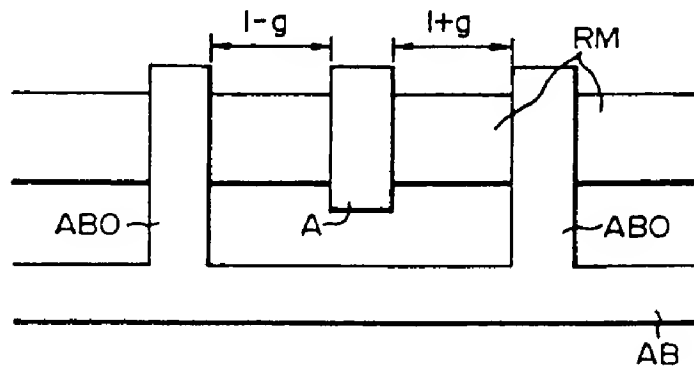


FIG. 56B

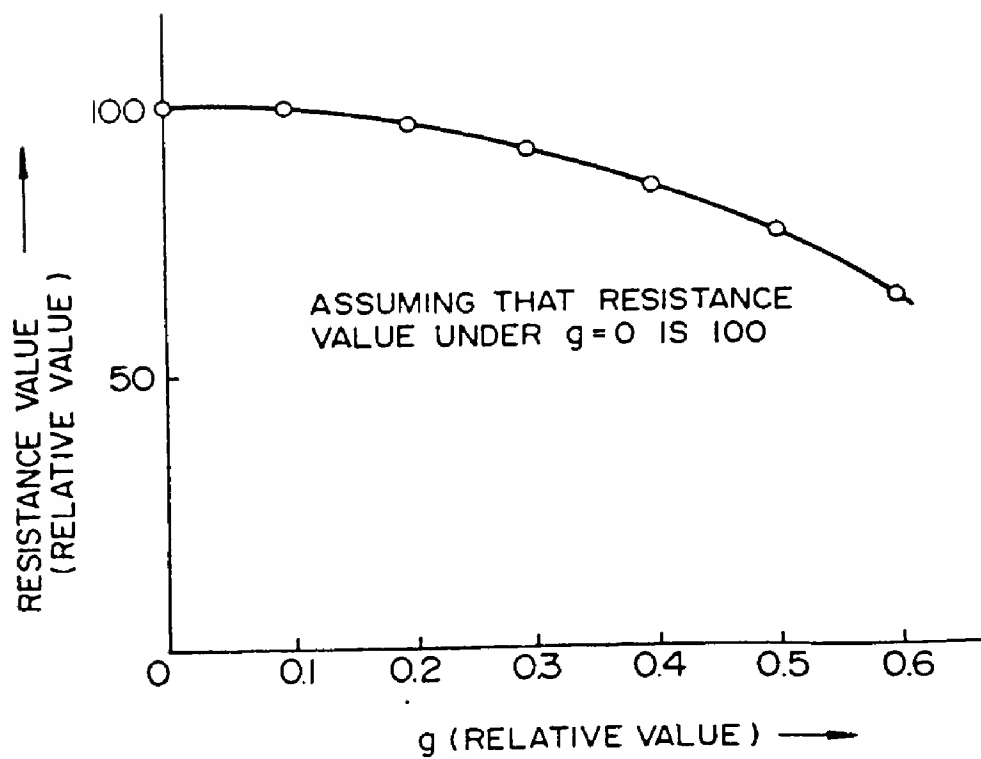
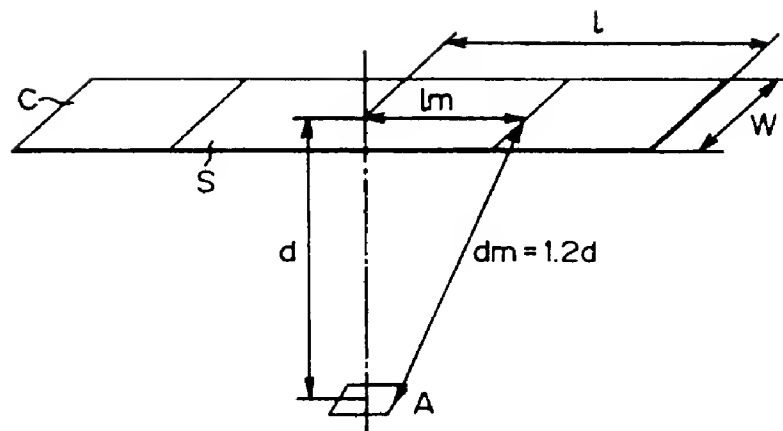


FIG. 57





European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 94 12 0109

| DOCUMENTS CONSIDERED TO BE RELEVANT | | | |
|---|--|--|---|
| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int. CL.5) |
| X | PROCEEDINGS OF THE SID., vol.31, no.4, 1990, NEW YORK US pages 349 - 354 S. MIKOSHIBA ET AL. 'Mechanism of discharge build-up and high-speed addressing of a Townsend-discharge panel TV using pre-discharges.' * page 349 - page 350 * | 1-5 | H01J17/49 H01J17/20 |
| D,X | ANNUAL CONVENTION OF THE INSTITUTE OF TELEVISION ENGINEERS OF JAPAN, no.4-3, 1990, TOKYO, JP pages 77 - 78 TAKANO ET AL. 'Plasma display panel with a resistor in each cell.' * abstract; figure 1; table 1 * | 1-5 | |
| D,A | US-A-4 780 644 (SAKAI ET AL.) * column 5, line 52 - column 6, line 3 * * column 7, line 5 - column 8, line 35; figures 3,7 * | 1,4 | |
| | | | TECHNICAL FIELDS SEARCHED (Int. CL.5) |
| | | | H01J |
| The present search report has been drawn up for all claims | | | |
| Place of search THE HAGUE | | Date of completion of the search 31 January 1995 | Examiner Schaub, G |
| CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document | | I : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document | |

